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Pitout JDD, Church DL, Gregson DB, Chow BL, McCracken M, Mulvey M, Laupland KB (2007). Molecular epidemiology of CTXM-producing Escherichia coli in the Calgary Health Region: emergence of CTX-M-15-producing isolates. Antimicrob. Agents Chemother. 51: 1281-1286.

Pelczar JR, Harley JP, Klein DA (1993). Microbiology: Concepts and Applications. McGraw-Hill Inc., New York, pp. 591-603.

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*Full Length Research Paper*

# Assessment of water quality of traditionally protected and unprotected rivers, streams and ponds in the Niger Delta, Nigeria

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**Water quality of some traditionally protected water bodies (Obi Pond, Abua Lake, Usede Lake, Atochi Stream and River Ethiope (Source) and unprotected water bodies (Ame-Oghene Pond, Oguta Lake, Omoku Pond, Tenmako Lake and Ikarama Lake) that commonly serve for domestic and drinking purposes in the Niger Delta area of Nigeria have been studied. The purpose of this study was to compare the water quality of traditionally protected water bodies with unprotected water bodies. Water samples collected from the identified sources was experimentally determined using various laboratory methods. Study was carried out within the early rainy season (May to June) of 2013. The water quality of each of the water bodies was assessed using Malaysian water quality index (WQI) and results show that, the water quality of the traditionally protected Obi Pond, Abua Lake, Usede Lake, Atochi Stream and River Ethiope (Source) are 76.73, 76.13, 76.65, 77.04 and 81.25, respectively and belong to class II. Empirically, the water quality can be described as good. The WQI of unprotected Ame-Oghene Pond, Oguta Lake, Tenmako Lake, Ikarama Lake and Omoku Pond are 65.64, 67.46, 37.60, 43.38 and 65.81, respectively. Water quality of Ame-Oghene Pond, Oguta Lake and Omoku Pond belong to Class III and can empirically be described as medium or average while the water quality of Tenmako Lake and Ikarama Lake belong to Class IV and can be empirically described as fair. Using the two-tailed T-test formula to evaluate the null hypotheses, results showed that the calculated t-value was 123.98 while that obtained from the t-Tables at 95% confidence level was 2.31 and hence the null hypotheses was rejected. This means that there is significant difference between the water quality of traditionally protected water bodies and the unprotected water bodies. We are of the view that by incorporating natural sacred sites into the existing protected area networks will improve natural resource conservation**.

**Key words:** Malaysian water quality index, traditionally protected water bodies, unprotected water bodies, sacred groves, gods/spirits, traditional ecological knowledge.

## INTRODUCTION

Protected areas are thought to be the cornerstones of biodiversity conservation and the safest strongholds for wildlife (Bruner et al., 2001). Biodiversity species can be protected using the instrument of government and

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traditional beliefs systems. In Nigeria, existing Government protected areas system has two major shortcomings. First, protected areas do not cover certain critical habitats and species because they are often located on land that has no other use. Secondly, is the obvious lack of capacity to implement protection policies. The management of protected areas is often ineffective inpreventing human encroachment. The exclusion of local people is believed to be one of the reasons why protected areas are ineffective, despite the large sums of money and manpower invested in them (Brown, 2003).

The traditional protection of sacred sites, viewed by indigenous people with special social-spiritual context, is found in different ethnic groups throughout the world (Dudley et al., 2006). They occur in various forms and at various spatial scales, such as a single plant species (Colding and Folke, 2001), burial grounds (Wadley and Colfer, 2004), sacred groves (Malhotra, 2001), and even animals or lakes used for religious worship (Rim-Rukeh et al., 2013). Sacred sites have been under the protection of local people for their spiritual value for generations and might be the oldest forms of protected areas in human history (Dudley et al., 2006). It has been shown that the traditional practice of sacred site worship may make significant contributions to protecting endangered species and conserving biodiversity (Bossart et al., 2006), and few studies have documented the social mechanisms behind those traditional practices (Malhotra, 2001).

Traditional ecological knowledge (TEK) has been defined as "a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relation of living beings (including humans) with one another and with their environment" (Berkes et al., 2000). Since the 1980s a growing literature within environmental sciences, ecological anthropology, and resilience theory has stressed the potential role of traditional knowledge for nature conservation and sustainable natural resource management (Toledo, 2002; Turner and Berkes, 2006).

Natural sacred sites, protected by local traditions abound in the Niger Delta area of Nigeria, nevertheless, our knowledge and documentation on the spatial distribution and management of the sacred sites is still poor. In addition, most rural settings in the Niger Delta area major sources of water for drinking and domestic purposes are: rivers/creeks/streams/ponds, hand-dug wells and harvested rain water (FGN, 2000). Studies on the physico-chemical composition of streams and rivers in the study area abound while information on the protection of such water bodies are still scarce and limited. In the study area water bodies that serve the purpose of drinking and domestic activities abound. The objective of the paper therefore is to find out whether or not traditionally protected water bodies have a better quality than unprotected water bodies. The outcome of the study will serve as the starting point for incorporating natural sacred sites into the existing protected area networks and the effectiveness of these networks in achieving conservation objectives could be improved.

## MATERIALS AND METHODS

### Study area

The study area is the Niger Delta region of Nigeria. It is located within latitude $5°45^1$ to $6°35^1$ and longitude $4°50^1$ to $5°15^1$ in the Southern part of the country. Geopolitically, the Niger Delta comprised of oil producing states: Abia, Akwa-Ibom, Bayelsa, Cross-River, Delta, Edo, Imo, Ondo and Rivers (Figure 1). It covers an estimated area of about 70,000 $km^2$ which accounts for about 8% of Nigeria's land mass (Okoko and Nna, 1998). The petroleum Industry in Nigeria is located in the Niger Delta area, with distribution of oil fields. The area accounts for about 90% of Nigeria's gross earnings as the production and exports of oil and gas play a dominant role in her economy (Okoko and Nna, 1998).

Previous study of the meteorology of the area (Gobo, 1998), reveals the average atmospheric temperature to be 25.50°C in the rainy season and 30.00°C in the dry season. The daily relative humidity values range from 55.50% in dry season to 96.00% in rainy season. Rainfall in the area averages 2500 mm annually. The rainfall pattern shows two identifiable seasons; the rainy season (April to October) and the relatively short dry season (November to March).

The area is a vast flood plain built by accumulation of sedimentary deposits washed down the Niger and Benue rivers. The Niger Delta area is the largest wetland in West Africa and one of the largest mangrove forests in the world (Darafeka, 2003). The area is criss crossed with numerous rivers, streams, tributaries, creeks and creeklets. Human settlement pattern is linear along the bank of the rivers.

Five (5) traditionally protected water bodies (Rivers, streams and lakes) and Five (5) unprotected water bodies (rivers, streams and lakes) that serve as the source of water for domestic and drinking purposes were selected within the study area. All sampling points were geo-referenced (Tables 1 and 2).

Water for the study was sampled according to the method of APHA (1998). At each of the selected water bodies, samples were collected from 5 (five) random points and composited to form a uniform representative sample for that location and taken to the laboratory for analyses. Water samples were collected in plastic containers pre-treated by washing them with 0.1 M dilute hydrochloric acid and sun-dried. At each sample collection point, the plastic containers were first of all rinsed with the water to be collected. One container at a time, with its lid closed was then dipped into the water body to a depth of about 1.0 m and the lid removed to fill the container with water. (The choice of 1.0 m was based (RPI, 1995), on the average depth of water bodies in the study area which is about 4.6 m and the fact that physico-chemical and biological parameters variability at such depths are negligible (Puyate and Rim-rukeh, 2008).

At each of the sample collection sites, a record was kept on the sample container indicating date, time, and location of sampling. Samples were properly handled and all necessary quality assurance and quality control (QA/QC) measures such as preservation, storage, and labeling, were taken. All sample containers were pretreated by washing in dilute hydrochloric acid and rinsed with distilled water. Winklers bottles were used to collect samples for biochemical oxygen demand (BOD) measurements. Fast changing parameters such as pH, temperature, colour, taste, odour, dissolved oxygen (DO), total dissolved solids (TDS), turbidity and electrical conductivity (EC) were measured in-situ using a multi-parameter water quality monitor (model 6000 UPG). At the determination of any of these parameters the instrument was properly checked and

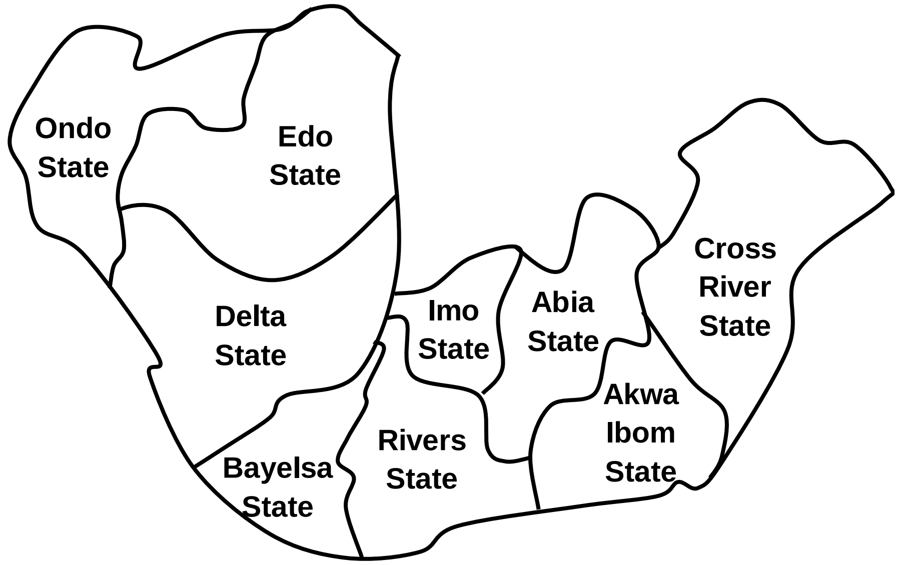


**Figure 1.** Geopolitical map of the Niger Delta Area.

**Table 1.** Traditionally protected water bodies in the Niger Delta Area.

| Location/Community | Coordinate | | Local Government Area/State | Native name of the water body |
|---|---|---|---|---|
| | Northing | Easting | | |
| Okorobi | 195509.06 | 379922.04 | Ethiope East/Delta | Obi Lake |
| Asaba-Ase | 249629.18 | 416242.11 | Ndokwa East/Delta | Usede Pond |
| Umuaja (Source of River Ethiope) | 213671.10 | 407331.09 | Ukwani/Delta | Ethiope River |
| Ishague | 256671.38 | 437731.73 | Aniocha South/Delta | Atochi Stream |
| Abua | 837841.72 | 478189.55 | Abua-Odua/Rivers | Abua Lake |

**Table 2.** Unprotected water bodies in the Niger Delta Area.

| Location/Community | Coordinate | | Local Government Area/State | Native name of the water body |
|---|---|---|---|---|
| | Northing | Easting | | |
| Ikarama | 143242.16 | 474506.31 | Yenagoa/ Bayelsa | Ikarama Lake |
| Ovierie -Ovu | 195571.16 | 379929.07 | Ethiope East/ Delta | Omoku Pond |
| Ugheghe | 195593.18 | 379935.02 | Ughelli South/ Delta | Ame - Oghene |
| Oguta | 178000.33 | 470500.12 | Oguta/Imo | Oguta Lake |
| Tenmako | 119120.82 | 388021.02 | Southern Ijaw/Bayelsa | Tenmako Lake |

calibrated. All water samples for the study were collected within the early rainy season (May to June) of 2013 and taken to Federal University of Petroleum Resources, Department of Environmental Sciences Laboratory for analysis.

In the laboratory, samples were analyzed for: BOD, chemical oxygen demand (COD), suspended solids (SS), ammonical nitrogen (AN), total phosphorus (TP) and total fecal coliform counts (TFCC). TSS was determined using the mass loss technique (APHA 209D - Total Non-filtrate Residual Dried at 103 to 105°C. The oven dried (at 105°C for 1 h) filter paper was used instead of glass fibre filter. The dried filter paper was weighed and then used to filter 100 ml of the sample. The filter paper and the residue were then dried in the oven at 105°C for 1 h and allowed to cool. The paper and residue was then weighed and recorded). BOD was determined using iodometric method while Ammonical Nitrogen was determined using Brucine colourimeter method. Total phosphate (TP) was determined using spectrophotometric method. For fecal coliform samples, 3 dilutions were prepared and analyzed by the membrane filtration method in triplicate. All methods of analyses were consistent with APHA (1998), FMENV (2002) and WHO (1984).

The water quality at each of the sampling location was assessed using the Malaysian Water Quality Index (WQI) as reported (DOE, 2005). Equation 1 gives the water quality index. The index considers six parameters. The parameters which have been chosen are DO, BOD, COD, TSS, pH value (pH), and AN (Khuan et al., 2002). The parameters and the weightage were assigned to each parameter.

The WQI approved by the Malaysian DOE (Equation 1) is calculated based on the above six parameters. Among them DO carries maximum weightage of 0.22 and pH carries the minimum of 0.12 in the WQI equation. The WQI equation eventually consists of the subindexes, which are calculated according to the best-fit relations given in Equations 2 to 7. The formulae used in the calculation of WQI are:

$$WQI = 0.22\ SI_{DO} + 0.19\ SI_{BOD} + 0.16\ SI_{COD} + 0.16\ SI_{TSS} + 0.15\ SI_{AN} + 0.12\ SI_{pH} \quad (1)$$

Where,

WQI = Water quality index (dimensionless unit);
$SI_{DO}$ = Sub-index of DO;
$SI_{BOD}$ = Sub-index of BOD;
$SI_{COD}$ = Sub-index of COD;
$SI_{AN}$ = Sub-index of AN;
$SI_{TSS}$ = Sub-index of TSS;
SIpH = Sub-index of pH.

**Sub-index for DO (in % saturation)**

$SI_{DO}$ = 0 for DO < 8 (2a)
= 100 for DO > 92 (2b)
= $-0.395 + 0.030DO^2 - 0.00020DO^3$ for 8 < DO < 92 (2c)

**Sub-index for BOD**

$SI_{BOD}$ = 100.4 - 4.23BOD for BOD < 5 (3a)
= 108e-0.055BOD - 0.1BOD for BOD > 5 (3b)

**Sub-index for COD**

$SI_{COD}$ = -1.33COD + 99.1 for COD < 20 (4a)
= 103e-0.0157COD - 0.04COD for COD > 20 (4b)

**Sub-index for AN**

$SI_{AN}$ = 100.5 - 105AN for AN < 0.3 (5a)
= 94e-0.573AN - 5 (AN - 2) for 0.3 < AN < 4 (5b)
= 0 for AN > 4 (5c)

**Sub-index for TSS**

$SI_{TSS}$ = 97.5e-0.00676SS + 0.05SS for SS < 100 (6a)
= 71e-0.0016SS - 0.015SS for 100 < SS < 1000 (6b)
= 0 for SS > 1000 (6c)

**Sub-index for pH**

SIpH = $17.2 - 17.2pH + 5.02pH^2$ for pH < 5.5 (7a)
= $-242 + 95.5pH - 6.67pH^2$ for 5.5 < pH < 7 (7b)
= $-181 + 82.4pH - 6.05pH^2$ for 7 < pH < 8.75 (7c)
= 536 - 77.0pH + 2.76pH2 for pH > 8.75 (7d)

Based on the Malaysian WQI, water quality is classified according to one of the following categories shown in the Table 3.

Generally, based on Malaysian WQI water quality is classified as follows:

**WQI Quality of water**

91 - 100 Excellent
71 - 90 Good
51 - 70 Medium or average
26 - 50 Fair
0 - 25 Poor

**Statistical analyses**

To evaluate whether or not that traditionally protected water bodies has a better quality than unprotected water bodies, null hypotheses ($H_o$) was formulated and tested using a two-tailed t-test distribution (Equation 8).

The null hypotheses ($H_o$): There is no significant difference between the water quality of traditionally protected water bodies and unprotected water bodies.

$$T = \frac{X - Y}{\sqrt{\frac{\sigma x^2}{Nx} + \frac{\sigma y^2}{Ny}}} \quad (8)$$

Where,
$Nx$ = Sample size of X
$Y$ = Mean WQI value of unprotected water bodies
$X$ = Mean WQI value of protected water bodies
$Ny$ = Sample size of Y
$\sigma y$ = Standard deviation of y
$\sigma x$ = Standard deviation of x

## RESULTS AND DISCUSSION

Results indicating the physico-chemical and biological characteristics of the studied water bodies (traditionally protected and unprotected rivers, streams and ponds) are presented in Table 4.

Results of the assessment of the water quality of the surface water bodies using the water quality index as reported (DOE, 2005) are presented in Table 4. Using the water quality index, the water quality of the traditionally protected Obi Pond, Abua Lake, Usede Lake, Atochi Stream and River Ethiope (Source) are 76.73, 76.13, 76.65, 77.04 and 81.25, respectively and belong to class II. Empirically, the water quality can be described as good.

Using the water quality index, the water quality of unprotected Ame-Oghene Pond, Oguta Lake, Tenmako Lake, Ikarama Lake and Omoku Pond are 65.64, 67.46, 37.60, 43.38 and 65.81, respectively. Water quality of Ame-Oghene Pond, Oguta Lake and Omoku Pond belong to Class III and can empirically be described as medium or average while the water quality of Tenmako Lake and Ikarama Lake belong to Class IV and can be empirically described as fair.

Using the water quality index as reported (DOE, 2005) showed that traditionally protected water bodies have better water quality than unprotected water bodies. However, we are of the view that such observation may have occurred by chance. To test the validity of such findings we statistically tested the outcome using a two-tailed t-test formula (Equation 8). Result showed that the calculated t-value was 123.98 while that obtained from the t-Tables at 95% confidence level was 2.31. Since the calculated t - value was higher than the t-Table value we therefore rejected the null hypotheses. This means that there is significant difference between the water quality of traditionally protected water bodies and the unprotected

**Table 3.** Classes in Malaysian Water Quality Index (DOE, 2005).

| Parameter | Class | | | | |
|---|---|---|---|---|---|
| | I | II | III | IV | V |
| AN | < 0.1 | 0.1 - 0.3 | 0.3 - 0.9 | 0.9 - 2.7 | >2.7 |
| BOD | <1 | 1 - 3 | 3 -6 | 6 - 12 | >12 |
| COD | <10 | 10 - 25 | 25 - 50 | 50 -100 | >100 |
| DO | >7 | 5 - 7 | 1 - 5 | 1 - 3 | <1 |
| pH | >7 | 6 - 7 | 5 - 6 | <5 | <5 |
| TSS | <2.5 | 25 - 50 | 50 - 150 | 30 - 50 | >300 |
| WQI | >92.7 | 76.5 - 92.7 | 51.9 - 76.5 | 31 - 51.9 | <31.0 |

water bodies.

The good water quality of the traditionally protected water bodies of *Obi* pond, River Ethiope (at the source), Atochi stream, Abua Lake and *Usede* Lake may have stemmed from the role of traditional beliefs in the conservation of natural resources (Berkes et al., 2000; Turner et al., 2000; Shastri et al., 2002). Traditional conservation ethics are capable of protecting biodiversity species in particular and the environment in general as long as the local communities have a stake in it. In fact, traditional ecological knowledge (TEK) systems are infused with practices and concepts, and modes of teaching and learning that can be related directly and indirectly to resource stewardship and conservation at various scales.

At the "*Obi*" pond popularly called *Obi* Lake, it is believed that the Obi spirit inhabits the water body. There is the traditional Obi cult in the community with a juju priest in charge of offering sacrifices to the Obi god. Usually membership into this group is on strict quailfication with terms and condition of membership strictly spelt out and passed down to community members for onward transmission to their children while growing up. Most often the process of initiation is a transitive one, from adolescent to adulthood and done in the night deep inside the shire.

Felling of trees or fuel wood collection within thirty meters radius from the pond is strictly prohibited. This principles though unknown was meant to preserve the watershed and the surrounding vegetation, this consequently checks the amount of evapotranspiration and allows some amount of tolerable water temperature for both micro and aquatic organisms to continue their ecosystem services for the enrichment of the soil, continuous supply of water and the healthy growth of the forest. The vegetation cover also helped to keep the water cool and fresh for drinking. Bathing and washing of clothes around, near or inside the pond is not allowed. Fishing or harvesting any aquatic animals within the pond are not allowed.

Reasons abound for this law, spanning from the respect for the *Obi* god who protect the pond and the organisms helping to purifying the pond and keeping the pond alive and also control the spread of diseases. Silence is observed while fetching water from the pond because it is believed that while speaking, an infected person may spill or splash saliva, so an infected person with tuberculosis or whooping cough for example may spill infected saliva containing the bacteria into the water. In addition this rule ensured the gods were not provoked to anger. Their anger could result in the pond drying up. Other taboos, such as the disallowing of menstruating women to collect water from the pond, prevent the defilement of pond deity and the issue of menstrual blood in traditional beliefs has been treated extensively in anthropology as a source of potent force (McLeod, 1981).

At the source of River Ethiope there is a tree that is believed to have existed over 1000 years. The roots of the tree create an avenue from which the groundwater stored in the aquifer finds its way to the surface from where the water flows to form the River. The tree is regarded as sacred grove and an abode of gods. Spiritual activities at the sacred grove are controlled by chief priest who is in charge of the abode of such god and who also is the messenger of the god in human form. The source of the river is also revered and protected because it is regarded as the source of life and fertility; barren women go to bathe in these waters in the hope of being fertile. The River and their immediate surroundings, especially forest, are protected on the basis that the spirit of the river resided in the area. The responsibility for protecting the grove is vested in the entire community, but a selected group of people or family normally takes the duty to enforce the rules. The conservation strategy, which is one of preservation, is enshrined in taboos, totems and sacrileges and other numerous cultural and religious rites and is maintained through reverence for the gods and ancestral spirits. These traditional guards regularly patrol the periphery of the grove and arrest intruders, who are reported to the chief priest for the necessary customary sanctions. The sanctions, which are done for the purpose of pacifying and purifying the gods and spirits, vary depending on the gravity of the offense. However, they usually consist of a cash fine, bottles of hot drinks, goats, sheep, chicken, kola nuts and alligator pepper as sacrifice to the gods.

Action that attracts the wraths of the god includes (i) felling of trees or fuel wood collection within twenty meters radius from the area is strictly prohibited. This principles though unknown was meant to preserve the watershed

**Table 4.** Physico-chemical and biological characteristics of studied water bodies in the Niger Delta Area, Nigeria.

| Parameter | Surface water bodies | | | | | | | | | | FMENV Regulatory for drinking water (1995) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Traditionally protected water bodies | | | | | Unprotected water bodies | | | | | |
| | Obi Lake | Abua Lake | Usede Pond | Atochi Stream | Ethiope River (Source) | Ame-Oghene Pond | Oguta Lake | Tenmako Lake | Ikarama Lake | Omoku Pond | |
| Colour (TCU) | 16.0 | 14.0 | 12.0 | 3.0 | 2.0 | 13.0 | 11.0 | 17.0 | 16.0 | 10.0 | - |
| Taste | Unobjectionable | Unobjectionable | Unobjectionable | Unobjectionable | Unobjectionable | Unobjectionable | Unobjectionable | Objectionable | Objectionable | Unobjectionable | Unobjectionable |
| Odour | Unobjectionable | Unobjectionable | Unobjectionable | Unobjectionable | Unobjectionable | Unobjectionable | Unobjectionable | Objectionable | Objectionable | Unobjectionable | Unobjectionable |
| pH | 7.4 | 7.1 | 7.1 | 6.9 | 6.9 | 7.2 | 6.8 | 5.1 | 5.9 | 6.6 | 6.5 - 8.5 |
| Temperature (°C) | 26.4 | 27.7 | 26.8 | 26.5 | 25.8 | 26.9 | 31.0 | 28.1 | 29.7 | 28.3 | 25 -30 |
| Turbidity(NTU) | 12.6 | 14.3 | 14.7 | 2.7 | 3.1 | 10.3 | 10.8 | 21.6 | 18.0 | 11.70 | 5.0 |
| Electrical Conductivity (µS/cm) | 14.7 | 15.4 | 11.3 | 23.7 | 6.80 | 11.7 | 16.5 | 21.4 | 24.8 | 13.5 | - |
| DO (mg/L) | 8.7 | 7.2 | 8.3 | 8.9 | 9.1 | 7.4 | 7.5 | 2.7 | 4.70 | 5.5 | >7.5 |
| COD (mg/L) | 1.90 | 2.3 | 2.1 | 1.30 | 0.97 | 1.48 | 2.1 | 21.5 | 15.3 | 6.6 | - |
| BOD (mg/L) | 1.10 | 1.60 | 1.00 | 0.98 | 0.60 | 1.32 | 1.40 | 17.3 | 10.7 | 1.90 | - |
| TDS (mg/L) | 57.3 | 47.6 | 61.8 | 12.8 | 8.50 | 13.4 | 37.4 | 184.0 | 63.7 | 33.8 | 2000 |
| SS (mg/L) | 9.70 | 24.6 | 10.3 | 8.60 | 5.50 | 9.30 | 13.3 | 37.3 | 23.7 | 21.1 | 50 |
| Total Phosphate (mg/L) | 0.73 | 1.86 | 0.86 | 0.33 | 0.177 | 2.40 | 0.08 | 2.47 | 1.66 | 1.61 | - |
| Ammonical nitrogen (mg/L) | 0.018 | 1.01 | 0.021 | 0.031 | 0.011 | 0.034 | 0.8 | 4.70 | 1.17 | 0.93 | - |
| Total Feacal coliforms (cfu/mL) | Nil | Nil | Nil | Nil | Nil | Nil | Nil | 2,175 | 750 | 230 | Nil |
| WQI | 76.73 | 76.13 | 76.65 | 77.04 | 81.25 | 65.64 | 67.46 | 37.60 | 43.38 | 65.81 | |

and the surrounding vegetation, this consequently checks the amount of evapotranspiration and allows some amount of tolerable water temperature for both micro and aquatic organisms to continue their ecosystem services for the enrichment of the soil, continuous supply of water and the healthy growth of the forest. The vegetation cover also helped to keep the water cool and fresh for drinking. This system protects the watershed from destruction. (ii) Bathing and washing of clothes around, near or inside the source of the River where drinking water is fetched was not allowed. (iii) Fishing or harvesting any aquatic animals within the source of the River is not allowed.

"*Usede"* pond is a mysterious pond harvested for fish species by the entire Ase kingdom once in ten years. The *Usede* pond is such that nobody goes there to fish alone within this period of ten years. Even if you go fishing alone, the punishment begins by having a bloated stomach and later death no matter the sacrifice made. So entrant into the pond alone is frightening. The reverence for the water body is due to presence of a god in the form a big fish with a string of cowry that have sighted during the fishing activities. The appearance of the big fish with a string of cowry signifies the end of the fishing festival and everybody inside the pond must be called out of the pond.

At Atochi stream by Ughelli - Asaba Road is regarded as sacred grove and an abode of the *mami -water goddess*. Spiritual activities at the sacred grove are controlled by chief priest who is in charge of the abode of such god and who also the messenger of the god in human form. The point is revered and protected because it is regarded as the fountain of life known for its potency to battle spirits of witches and wizards and the breaking of ancestral curses. The immediate surroundings, especially forest, are protected on the basis that the spirit of the stream resided in the area. The responsibility for protecting the grove is vested in the chief priest who is usually a woman. Although there are no reported actions against any one that defile the area, the water is revered because of its reported potency.

At Abua community is a mysterious pond (Abua Lake) harvested for fish species by the entire community once in seven years. The Abua Lake is such that nobody goes there to fish alone within this period of seven years. Even if you go fishing alone, the punishment begins by having a bloated stomach and later death no matter the sacrifice made. So entrant into the pond alone is frightening. The reverence for the water body because of the presence water goddess prevents community people from using the water resource indiscriminately.

## Conclusion

Here, we presented evidence of nature conservation through traditional belief systems from across the Niger Delta area of Nigeria drawing from the experience of traditionally protected water bodies and unprotected water bodies. Traditionally protected ecosystems can play a valuable role in natural resource conservation especially water bodies (rivers, streams, lakes and ponds) because of the local people's willingness to protect and conserve them. We are of the view that by incorporating natural sacred sites into the existing protected area networks, the effectiveness of these networks in achieving conservation objectives could be improved, by increasing the variety of protected habitats and by harnessing the support of local people.

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*Full Length Research Paper*

# The impact of water quality on species diversity and richness of macroinvertebrates in small water bodies in Lake Victoria Basin, Kenya

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**This study was carried out in small water bodies (SWBs) within Uasin-Gishu and Siaya Counties of Kenya to investigate the effects of water quality on species diversity and richness of macroinvertebrates in these areas. The water quality of the SWBs was assessed in two dams in Uasin-Gishu County (Kesses and Kerita) and the other two in Siaya County (Mauna and Yenga) within Lake Victoria Basin. Water samples for total phosphorus (TP) and total nitrogen (TN) were collected at each sampling station and analyzed using standard methods and procedures. Physico-chemical parameters such as dissolved oxygen (DO), pH and temperature were taken *in situ* using electronic meters while biological oxygen demand (BOD) was analyzed using Winkler method after 5-days incubation period. Macroinvertebrate samples were collected using a scoop net (500 µm mesh size) then transferred into a white tray for washing and sorting prior to identification. Preliminary tests of water quality parameters were evaluated by GLM analysis of variance of which very significant differences were observed for both spatial ($p$ = 0.004) and temporal ($p$= 0.001) variability with the measured water quality parameters. The results showed that there is both negative and positive change of macroinvertebrate composition and abundance between SWBs over time due to spatio-temporal variation of water quality parameters. Principle Component Analysis (PCA) further confirms this. PCA described over 90% of variation at the stations. For both seasons, TN, TP, temperature, pH, DO and BOD were found to have a significant influence of the species diversity, dominance and richness of macroinvertebrates. Principle component analysis of TN, TP, DO, pH and BOD for the SWBs described 96% of their variation when they were compared at temporal and spatial scales. This trend leads to the variation in species diversity; dominance and richness of macroinvertebrates in these SWBs. Water quality and littoral invertebrate mean relative abundance were significantly different among the studied small water bodies during the study period. Overall, water quality seemed to have had effect on species diversity, dominance and richness of the invertebrate benthic community therefore can be used as a bio-monitor to aquatic health.**

**Key words:** Water quality, macroinvertebrates, species diversity and richness, small water bodies, Lake Victoria basin.

## INTRODUCTION

Eutrophication due to poor water quality has been the most challenging global threat to the quality of our lakes as a result of excess nutrients getting their way through run off during rainy seasons (Likens, 2010). This process

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of enrichment with excess nutrients, primarily phosphorus and nitrogen, leads to enhanced growth of algae, periphyton and/or macrophytes, as well as increased biological productivity and decreased basin volume from the excessive addition of dissolved and particulate inorganic and organic materials to lakes and reservoirs (Cooke et al., 2005; Likens, 2010). Small water bodies in particular, which are primarily constructed for flood control and irrigation, are experiencing rapid eutrophication due to nutrient loading, sedimentation, acidification, and the introduction of toxic contaminants as a result of runoff water, within Lake Victoria basin lie watersheds dominated by agricultural production, which increases phosphorus-bound sediments in a reservoir, due in part to erosion.

Pollution of these aquatic environments is a significant global water quality management concern. Activities such as agriculture, silviculture, mining and urbanization produce contaminated runoff and excessive sediment that disturb physical habitat (Barbour et al., 1996). These activities combined with highly erodible soils and locally intense rainfall events create high potential for nonpoint source pollution in water bodies (U.S. Department of Agriculture, 1997). The amounts of nutrients in water also play a significant role in influencing the chemistry of aquatic ecosystems. As water flows over rocks and soils, it carries some nutrients in solution while others are adsorbed into sediments on their way (White et al., 2008). The most important nutrients are those that are often in short supply and those that limit primary species diversity of phytoplankton and macroinvertebrates, like phosphorus, nitrogen or both (Kalff, 2002).

The structure and function of aquatic organisms reflect physical/chemical conditions, and change with increased human influence (Karlson et al., 2002; Herrmann, 1999). For example, in most ecosystems they appear to be controlled mainly by temperature regimes, substratum types and hydraulic variables (Vannote et al*.,* 1980). In contrast, the macroinvertebrate communities of aquatic environments, particularly those in areas of variable climate, may be controlled more by stochastic processes of recruitment, dispersal, colonisation and local extinction, both of the macroinvertebrates themselves and of the macrophyte beds that provide much of their habitat (Batzer and Wissinger, 1996).

In addition, the main physico-chemical factors that affect aquatic environments are temperature, discharge, DO, pH, nutrients and specific conductivity (Hanninen et al., 2000; Boney, 1989). Temperature is an ecologically significant parameter that is known to influence the structure of aquatic communities (Giller and Malmsqvist, 1998). For example, through combined influences on dissolved oxygen and metabolic activity, temperature has critical effects on species' distributions (Rostgaard and Jacobsen, 2005) and density (Hogg and Williams, 1996). Temperature and dissolved oxygen levels usually fluctuate seasonally and aid in the structuring of benthic communities, which varies from species to species (Shieh and Yang, 2000). It also regulates the amount of dissolved oxygen in water (Kalff, 2002). Increase in temperature lowers its solubility resulting in low values.

Natural differences in pH and alkalinity may be important determinants of macroinvertebrate community structure in SWBs. Highly acidic water generally results in impoverishment of fauna, and low acidities reflect better buffering and higher productivity (Busulwa and Bailey, 2004). Dam acidification can alter community structure by being acutely or chronically damaging tissues of invertebrates particularly for species that easily loose sodium ions when pH is reduced (Shieh and Yang, 2000). Secondly, it alters algal communities, upon which some invertebrates depend for food and shelter, altering predation on invertebrates by decimating numbers of other crustaceans, fish, and amphibians, and by altering the bioavailability of some other potential stressors, such as heavy metals. Such effects may reduce invertebrate species diversity, increase the abundance of tolerant species and changed community composition (Shieh and Yang, 2000).

Aquatic macroinvertebrates have the ability to live under different levels of physico-chemical water conditions, and to occupy different substrata. In lowland areas high values of dissolved oxygen can be maintained by minimal interference from anthropogenic activities and the contribution by epilithic algae during photosynthesis.

Benthic macroinvertebrates are used largely in assessments of streams and rivers (Giller and Malmsqvist, 1998); but studies focused on macroinvertebrates as indicators in lakes and reservoirs are less common. Few studies (Griffith et al., 2005; Batzer and Wissinger, 1996) have been conducted to determine how communities within a water body respond to the changes in water quality, specifically macroinvertebrates in small water bodies. By comparing spatial and temporal data it can be determined if the macroinvertebrate community has been reset to its original composition and the impact of the water quality on the community. The objective of this paper was to determine any changes in the benthic macroinvertebrate community in response to change in water quality in small water bodies within Lake Victoria basin, Kenya during the study period.

## MATERIALS AND METHODS

### Study area

The study was carried out in SWBs within the Lake Victoria Basin which was stratified in terms of altitude difference, their sizes and continuous availability of water. The low altitude sites were represented by Yenga and Mauna Dams in Siaya county and high altitude by Kesses and Kerita Dams in Uasin-Gishu County (Figure 1).

Kesses dam is located at latitude and longitude of 00° 17. 263'N, and 035° 19.852'E, respectively (GPS readings, etrex Garmin model). The littoral zone was dominated by *Typha latifolia* and *Cyperus papyrus* species. In the shallow littoral areas, water lilies, *Nyphae lotus*, water fern, *Azolla* spp., water cabbage, *Pistia stratoites*, *Salvinia*, *Lemna*, *Ceratophylum dermersum, Potamogeton, Ultricularia* and *Najas* species are found. The dam is drained by

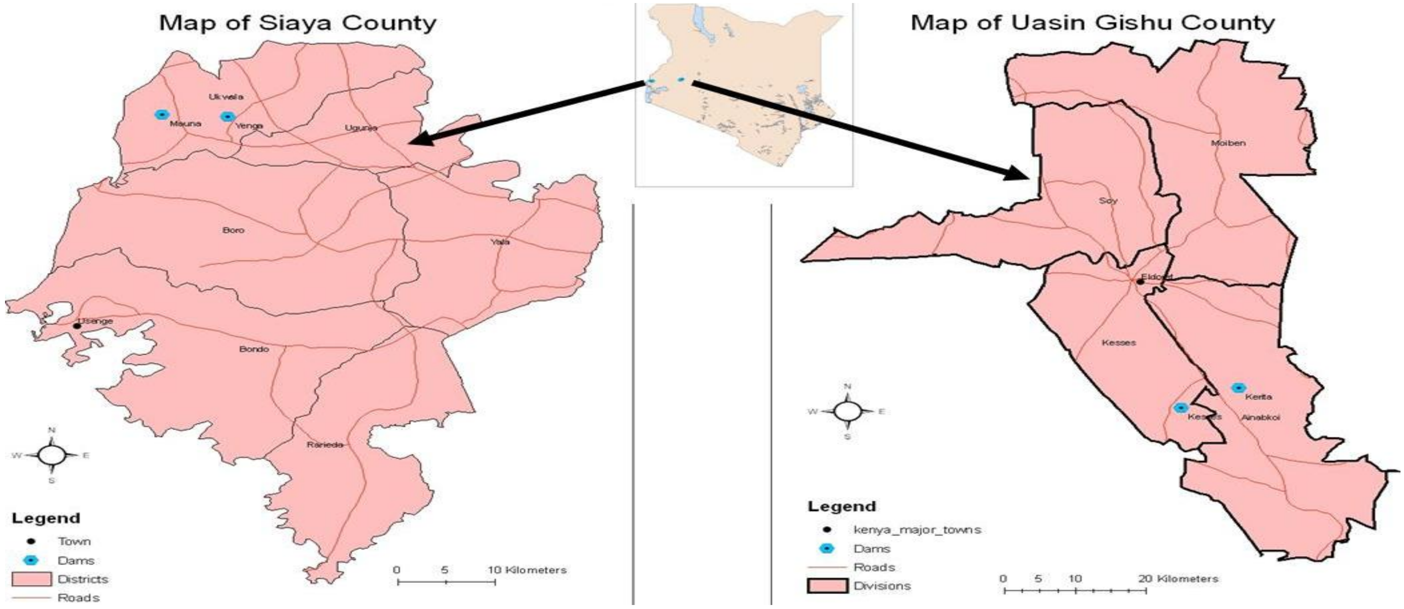


**Figure 1.** Location of Siaya and Uasin-Gishu counties with demarcations of small water bodies (Source: author).

two rivers from the east including Endaragwa and Endaragweta. It has a surface area of approximately 500 acres and a maximum depth of 4.48 m while Kerita lies at latitude and longitude of $00^0$ 19. 263'N, and $035^0$ 24.329'E, respectively (GPS readings, etrex Garmin model). The most noticeable emergent macrophytes in the littoral zone was dominated by *T. latifolia* and *C. papyrus.* It is also fed by two rivers, that is, River Chebolol entering in the south-east direction and Kabiyemit which enters the dam in the south-west direction. It has a surface area of approximately 25 acres and a maximum depth of 3 m (Ngodhe et al., 2013).

Yenga is located at latitude and longitude $00^0$ $13^{'}$ $03^{''}$N; $034^0$ $12^{'}$ $44^{''}$E, respectively. It has steep sided edges. The littoral zones are composed of sandy and rocky bottoms with loose macrophytic detrital and animal manure deposits brought in by surface runoff from the catchment characterize the littoral zones. The dam is dendritic in shape, has a seasonal feeder stream called Ugege and a permanent spillway. It has a surface area of approximately 15 acres and a maximum depth of 4.5 m. Mauna is situated at latitude and longitude of $00^0$ $12^{'}$ $358^{''}$N; $034^0$ $09^{'}$ $433^{''}$E, respectively. It has steep sided edges. The littoral zones are composed of sandy and rocky bottoms with emergent macrophytes such as *Typha* sp., *papyrus* sp., reeds and sedges dominated the zone. It has a surface area of approximately 35 acres and a maximum depth of 4 m (Ngodhe et al., 2013). Sampling was undertaken in each dam at monthly intervals from December 2010 till June 2011 on various sampling sites (Figure 2)

**Water quality**

Triplicate samples were collected at 10 cm below the water surface in each dam monthly at the chosen sampling sites (Figure 2). The physico-chemical parameters in the different microhabitats were measured *in situ,* temperature and pH were measured by a combined pH-and-temperature-meter (OAKTON$^R$, Model pH/Mv/ºC METER, Singapore). Two sets of triplicate water samples were collected in glass stoppered bottles at each sampling station for dissolved oxygen (DO) and biological oxygen demand (BOD) using Winkler's method (APHA, 1998). The first set used to determine DO was fixed using 2 ml manganous sulphate followed by 2 ml of Winkler's reagent.

Samples for determination of total phosphorus (TP) and total nitrogen (TN)) were collected using plastic sampling bottles of 500 ml. The samples were fixed with 3 drops of concentrated sulphuric acid in the field and transported in a cool-box to maintain the nitrogen balance to the laboratory for further analyses. Total nitrogen was determined using the Kjeldahl method in the laboratory (APHA, 2000). A 50 ml water sample was taken in a conical flask to which 2 ml of ammonium chloride solution was added. The solution was then mixed well. The first 10 ml of the sample was run through the cadmium column and discarded, and the following 25 ml of solution was collected in a conical flask to which 0.5 ml of sulphanilamide solution was added. After about 5 min, 0.5 ml of n-1 naphthyl- ethylene diamine dihydrochloride was added and the solution was mixed well. After 1.5 h, the absorbance of the solution was measured at a wavelength of 543 nm in a Spectrophotometer (Pharmacia Biotech model, 65455). A 50 ml of distilled water and different standard solution were also treated as above. Total nitrogen was calculated using the formula:

$$\text{TN in mg/L} = F\,(E_1 \text{ sample} - (E_0 + E_{B1})$$

Where

$$F = \frac{\text{Sample concentration (of } NO_3 \text{–N/1 in mg/L)}}{E_1 - E_{B1}}$$

$E_0$ = absorbance of sample without reductant; $E_{B1}$ = absorbance of distilled water + reagent; $E_1$ = absorbance of sample with reagent

Total phosphorus was measured using the persulfate digestion method (APHA, 2000). A 100 ml of mixed reagent was added to a flask with 100 ml of sample. Simultaneously, 10 ml of mixed reagent without reductant was added to another flask with 100 ml of sample and the sample thoroughly mixed. After 1.5 h, extinction coefficient of the solution was measured at a wavelength of 885 nm in a spectrophotometer (Pharmacia Biotech model, 65455). The absorbance of the reagent and distilled water blank was also measured. The total phosphorus content of the sample was calculated as follows:

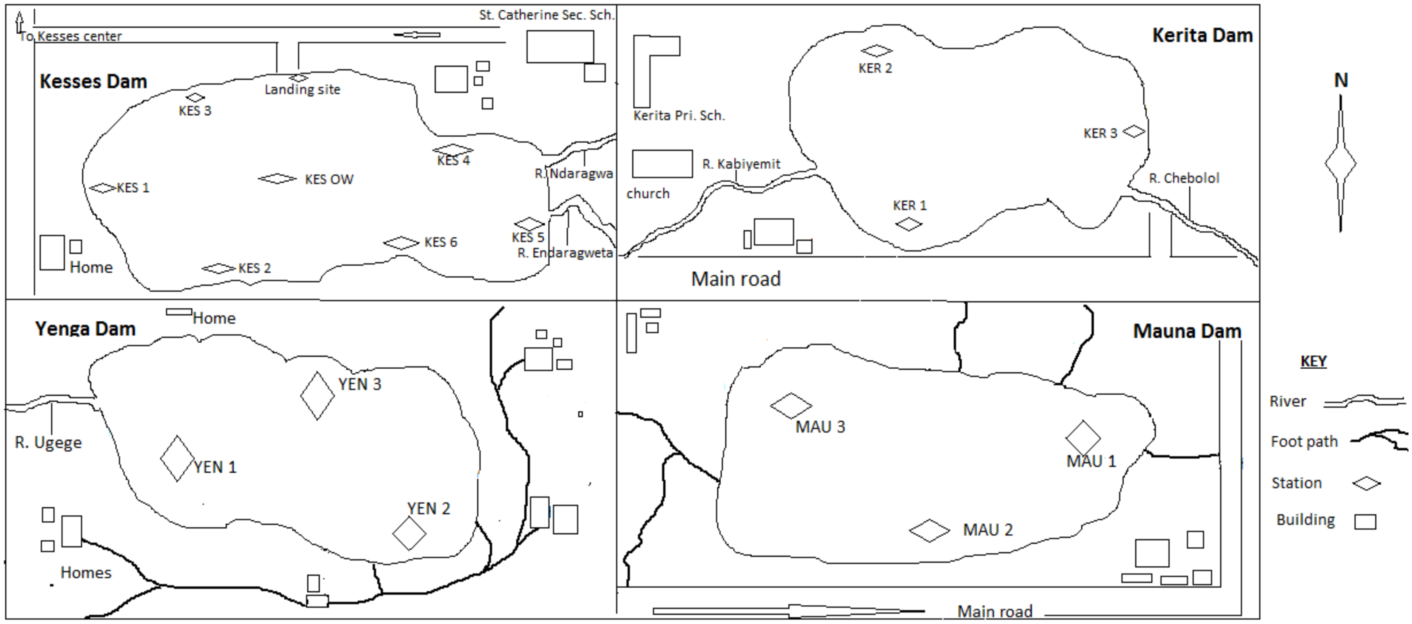


**Figure 2.** A sketch of the small water bodies showing the sampling sites (KES 1 = Kesses station 1, KES 2 = Kesses station 2, KES 3 = Kesses station 3, KES 4 = Kesses station 4, KES 5 = Kesses station 5, KES 6 = Kesses station 6, KES OW = Kesses open waters, KER 1 = Kerita station 1, KER 2 = Kerita station 2, KER 3 = Kerita station 3, YEN 1 = Yenga station 1, YEN 2 = Yenga station 2, YEN 3 = Yenga station 3, MAU 1 = Mauna station 1, MAU 2 = Mauna station 2 and MAU 3 = Mauna station 3).

TP in µg/L = F ($E_1$ sample – ($E_0$ + $E_{B1}$)

where:

$$F = \frac{\text{Sample concentration (of } PO_4 - P/l \text{ in µg/L)}}{E_1 - E_{B1}}$$

$E_0$ = absorbance of sample without reductant; $E_1$ = absorbance of sample with reductant; $E_{B1}$ = absorbance of distilled water + reagent.

### Macro invertebrates

Littoral macroinvertebrates were sampled using a scoop-net of 0.5 mm mesh size with 0.4 m diameter. The samples were sorted live in a white plastic tray and placed into vials and preserved with 70% ethanol. The samples were then transported to the laboratory for further sorting, counting and identified to genus level using identification keys (Merritt and Cummins, 1997; IFM, 2006).

### Data analysis

The mean, standard errors, line-graphs and bar graphs (classical analysis methods) were carried out to see the variation trend. Species richness, diversity (Simpson's) and dominance were calculated for comparison and prior analysis of any uniqueness or difference in the sampled biological community at different pollution gradient (Microsoft excel 2013 and Minitab 16). The diversity indices (Simpson diversity index and Dominance of the taxa at the sampled stations) were then computed for macro invertebrates using PAST statistical software. General linear model analysis of variance was also undertaken for the six water quality parameter mean measurements (temperature, DO, BOD, TN, TP and pH) to determine if there is any significant difference in these measurements among the stations, between the months, if there is any interaction between stations and the months sampled (using Minitab 16 software). Further analysis of the above six water quality parameters related to the stations was done with multivariate method using PAST Software. Principle component analysis of the Stations and six mean water quality parameters (temperature, DO, BOD, TN, TP and pH) measurements were evaluated for the variation of the stations with these measurements.

## RESULTS

### Water quality

The mean monthly values of physico-chemical parameters and nutrients recorded among the dams during this study are summarized in Figures 3 to 8. Mean pH change fluctuated at the four dams and at different months. Kesses dam reached its peak during January2011 and April 2011 but low values were recorded during December 2010 and June 2011. In Kerita Dam, the highest value was registered during the months of March and April 2011 with small variation during other months. Yenga Dam also fluctuates during the sampling periods with the peak during January 2011 and the same trend was also seen in Mauna Dam with the highest value registered during November 2010 and lowest in April and May 2011. All dams registered a pH value of above 7 in all months sampled.

Figure 4 shows the temperature variation during the

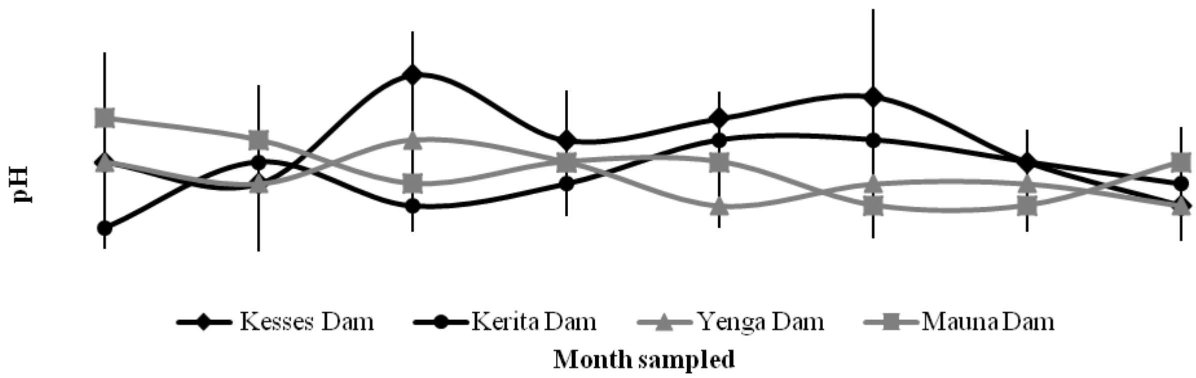


**Figure 3.** Mean±SE monthly pH values in small water bodies during the study period.

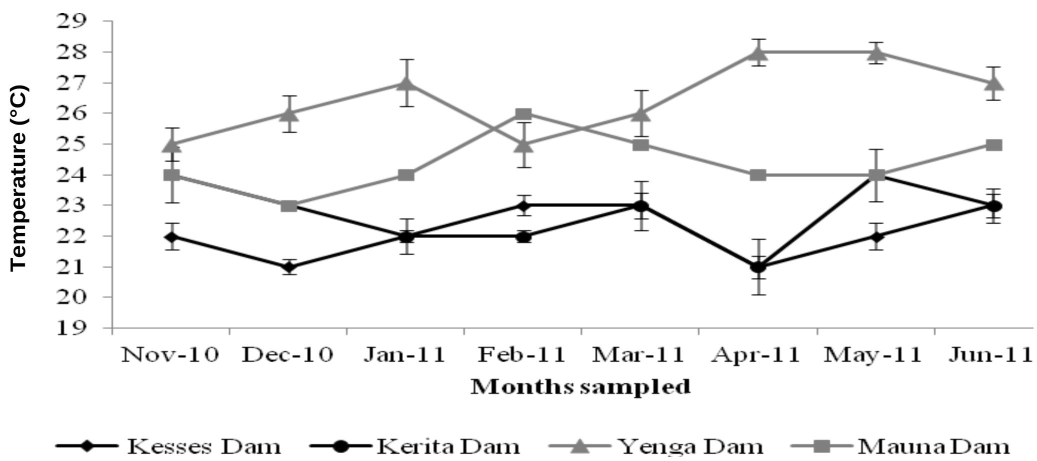


**Figure 4.** Mean±SE monthly temperature values in small water bodies during the study period.

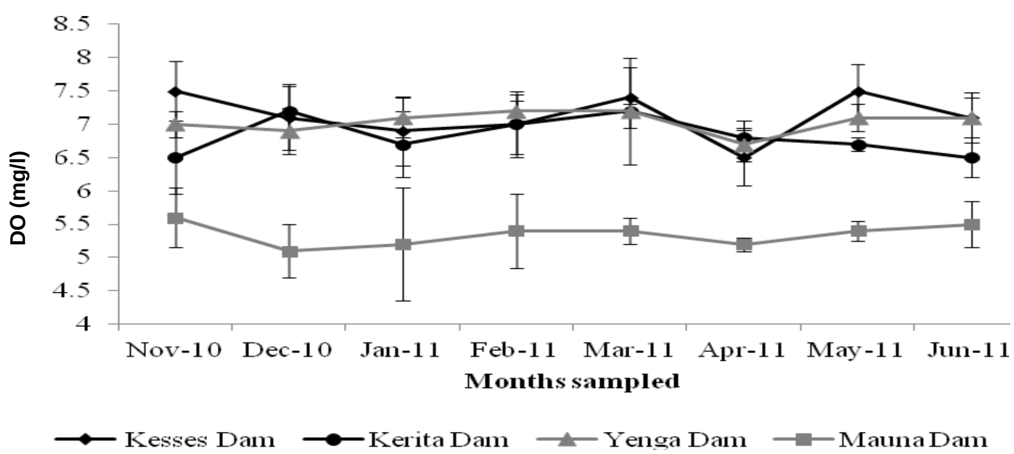


**Figure 5.** Mean±SE monthly DO values in small water bodies during the study period.

study period. The temperature values were high in the low altitude dams (Yenga and Mauna). The temperature values were recorded during the last three months (April, May and June 2011) in Yenga Dam while it was highest and lowest during the months of February 2011 and December 2010, respectively, in Mauna dam. In the high altitude dams (Kesses and Kerita), there was no clear trend with high values recorded during November 2010

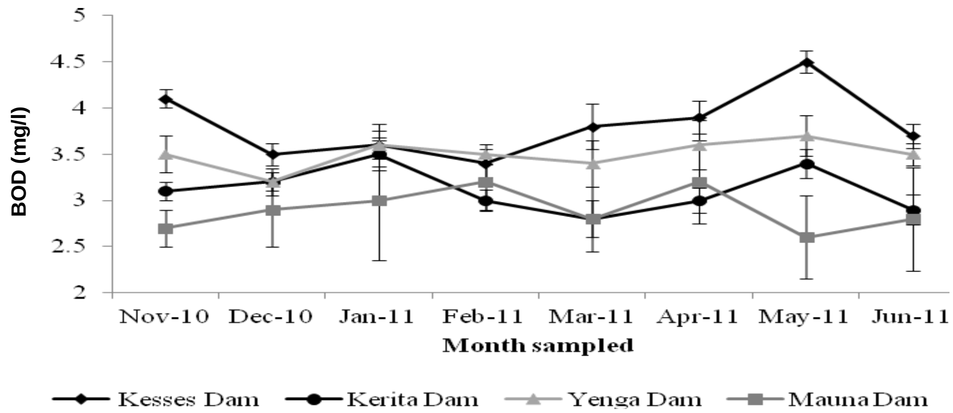


**Figure 6.** Mean ± SE monthly BOD values in small water bodies during the study period.

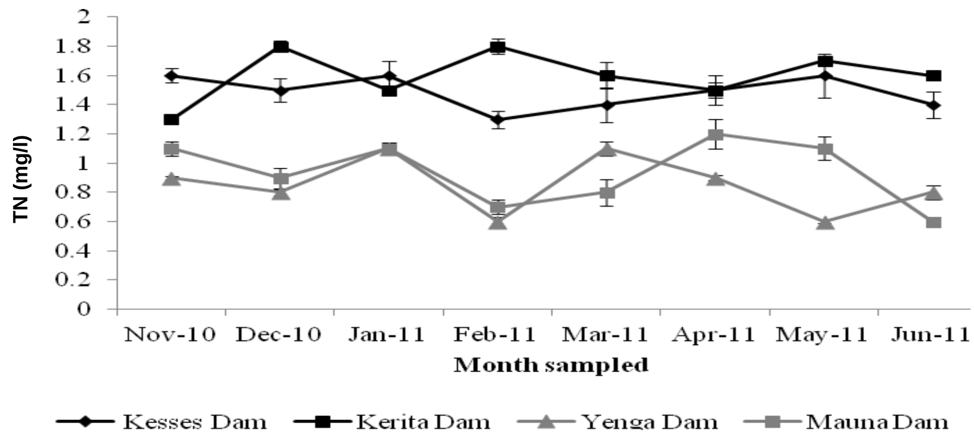


**Figure 7.** Mean±SE monthly total nitrogen (TN) values in small water bodies during the study period.

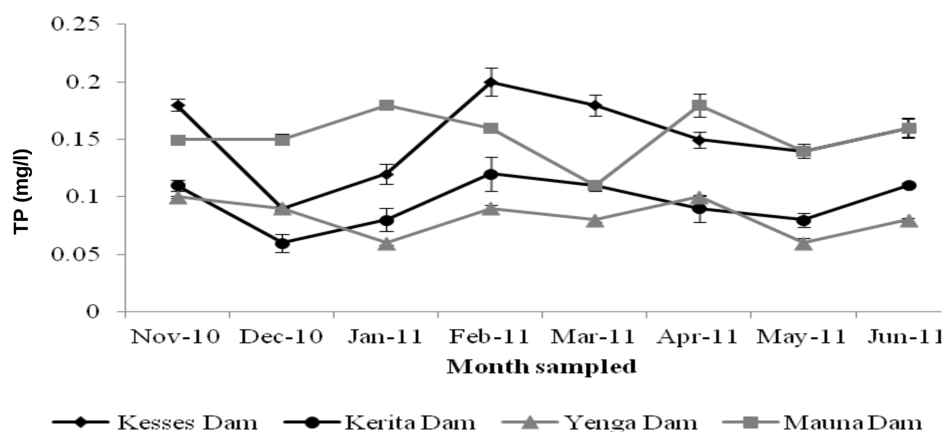


**Figure 8.** Mean±SE monthly total phosphorus (TP) values in small water bodies during the study period.

and May 2011 in Kerita while in Kesses the highest was registered during the months of March and June 2011.

Mean DO change also revealed a similar trend in all dams and at different months. Kesses Dam had November 2010, March and May 2011. There was a similar trend in Kerita and Yenga with slight differences in values recorded

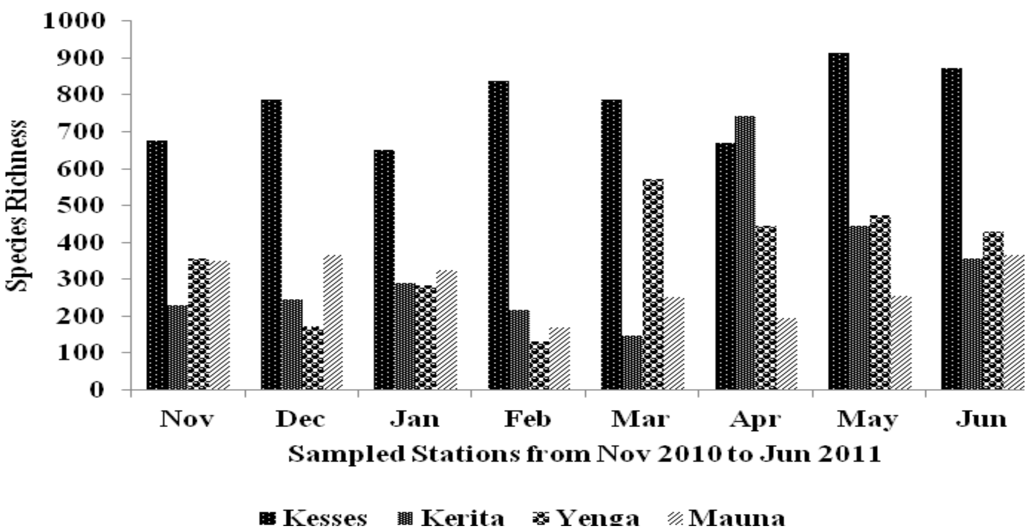


**Figure 9.** Species richness in small water bodies during the study period.

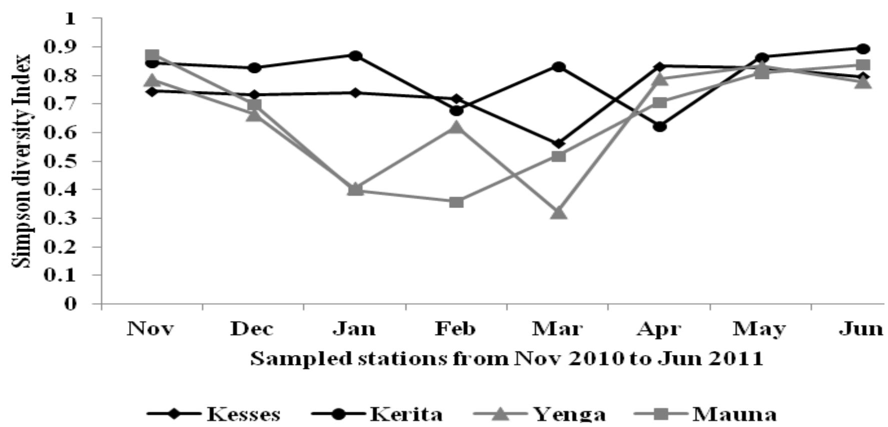


**Figure 10.** Simpson's diversity index of the macro invertebrates in SWBs during the sampling period.

in all months sampled. Mauna Dam was different from other three dams. It registered the lowest DO values throughout the study period with its highest recorded during the month of January 2010 with almost the same value during the other months (Figure 5).

Biological oxygen demand (BOD) values are shown in Figure 6. Kesses and Yenga dams registered the highest values, Kesses and Yenga reached their peak during the month of May 2011 while their lowest values were recorded during the months of December 2010 and February 2011. On the other hand, Kerita Dam had intermediate values with the highest value registered during the months of January 2011 and May 2011 while Mauna dam had the lowest BOD in all the studied months except during the month of February and April 2011 where the value was above what was seen in Kerita Dam. Both Mauna and Kerita registered the sam value of BOD during the month of March 2011 (Figure 6).

Total nitrogen (TN) was high in high altitude dams in all months samples, the highest values was recorded in Kerita during the months of December 2010 and February 2011 while the low altitude dams registered moderately high figures with a similar trend observed between the two dams (Yenga and Mauna) with their values being slightly above and below 1 (Figure 7). Total phosphorus (TP) did not follow the same trend as the values were highest in Kesses and Mauna dams unlike the other two dams where the values were low with a similar trend with Yenga having the lowest during the months of January and May 2011 (Figure 8).

The species richness in small water bodies during the study period is shown in Figure 9. Kesses Dam generally recorded the highest values with its peak reached during the month of May 2011. The richness was higher in Kesses than in all other small water bodies during the study period except during the month of April 2011 where Kerita Dam had the highest richness (Figure 9). The other dams did not vary much in terms of species richness

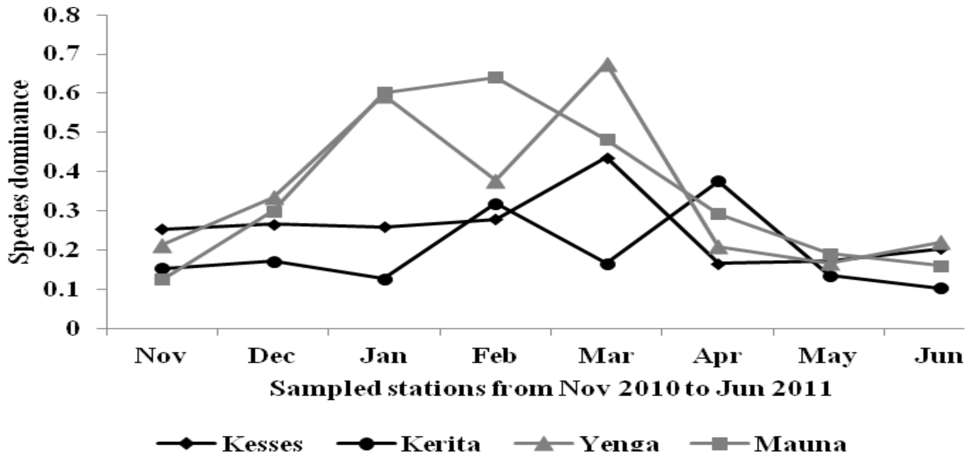


**Figure 11.** Species Dominance of the macro invertebrates in SWBs during the sampling period.

except during the month of March 2011 where Yenga dam was much higher than Kerita and Mauna (Figure 9). Simpson's diversity Index and dominance is shown in Figures 10 and 11. In general, all small water bodies had moderately high diversity indices in all months sampled except during the months of January, February and March 2011 where the diversity was low in Yenga and Mauna Dams (Figure 10). Dominance was high in Yenga and Mauna dams where there was up and down movement. There was low dominance in Kesses and Kerita as compared to other two dams though the values were constantly fluctuating throughout the study period with Kerita Dam recording the lowest of all in most months (Figure 11). General linear model revealed there was significant spatio-temporal difference in species diversity during the study period (p=0.004 and p=0.001) respectively.

The mean physico-chemical water quality parameter measurements were also compared during the study period as presented in Figure 12. Component 1 described 82.35% of this variation while component 2 had 14.34% variance. High TN, TP and pH influence was shown to be of significance with large Eigen-vector displacement along the horizontal axis and its influence was on Kesses and Kerita Dams. The same could be deduced with DO and BOD (positive coefficient) with component 1 that describes 82.35% of the variation among the dams; this is negative with respect to Mauna and Yenga Dams. Temperature positively affected Mauna and Yenga yet negatively influenced Kessess and Kerita with component 1. The combination of these two components explains 82.35 + 14.34 = 96.69% of the variation in water quality parameters among the dams (Figure 12).

## DISCUSSION

Water quality parameters such as DO, BOD and nutrients revealed a drastic increase and decrease in their concentrations for all water bodies sampled during the entire study period. This spatio-temporal change of water quality which could be attributed to different concentration of organic matter within a water body at a given point in time influenced the composition and distribution of macro invertebrates. This observation is supported by Peeters et al. (2004) and Orwa et al. (2013) who stated that the distribution and composition of aquatic macroinvertebrate communities are influenced by a variety of environmental factors such as habitat characteristics, water quality, sediment quality, food quality and quantity along with biological factors such as competition and predation. As these environmental and biological factors change over time, the macroinvertebrate community also changes. Physico-chemical parameters such as temperature, pH, DO, BOD and TN directly influenced the composition and abundance of macrointervertebrates. High temperature, low TN, low DO and high BOD negatively influenced the species diversity, dominance and richness in Yenga and Mauna Dams as they recorded low species diversity and richness as compared to Kesses and Kerita Dams which had low temperatures, high TN, high DO and low BOD resulting in high species richness. TP and pH did not show any clear effects on macroinvertebrate diversity and richness. The changes of species diversity and richness were probably due to variation in the tolerance level of environmental degradation due to anthropogenic impacts observed in the dams. This could conform to the physical structure that could have provoked perturbations in aquatic invertebrate communities, but the response to such events varies according to species. This is also supported by Kari and Rauno (1993), Griffith et al. (2005) and Orwa et al. (2013) who concluded that the distribution of aquatic macroinvertebrate occurrence is set by physical and chemical tolerance of the individual macro invertebrates to an array of environmental factors. A lower value of the diversity index is generally interpreted as characteristic of polluted conditions over time, where a few tolerant genera dominate the community while higher values are recorded in unpolluted waters. Low species diversity was observed during high temperatures, low DO and high

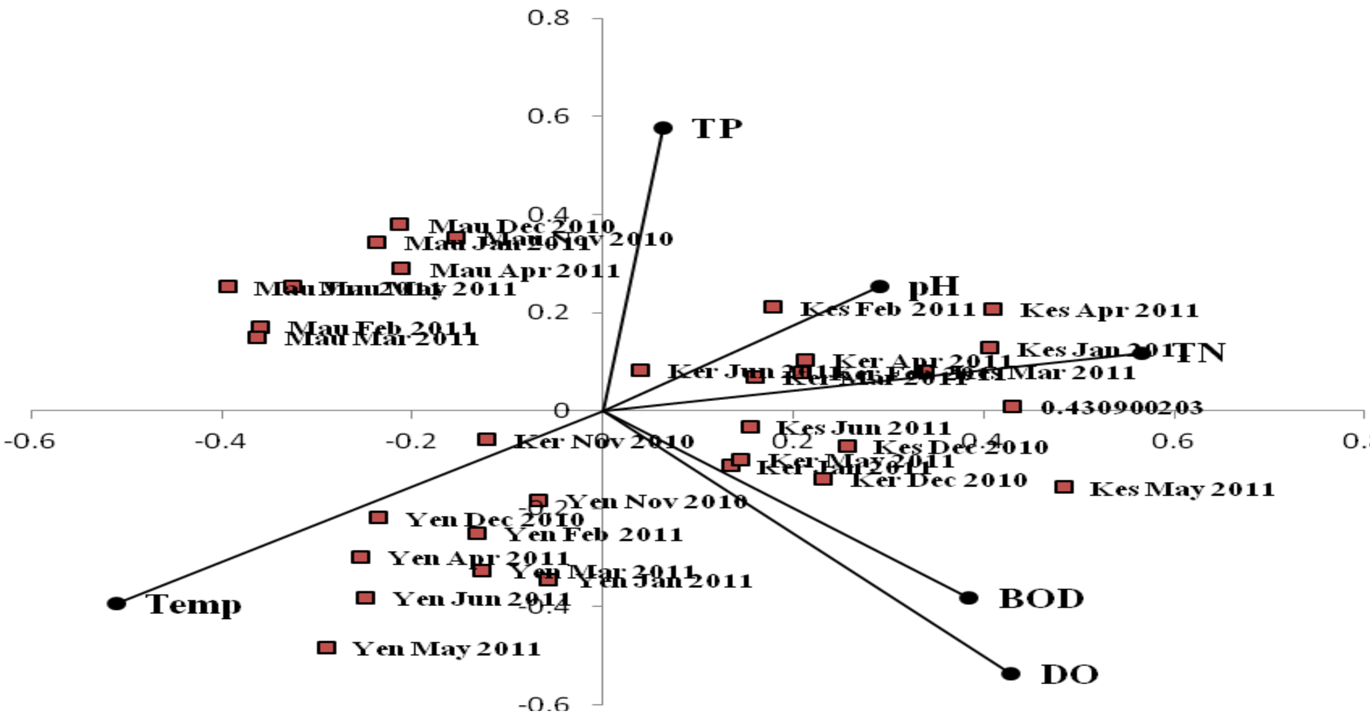


**Figure 12.** Principle component analysis of the mean water quality parameters during the study period.

BOD in Yenga and Mauna Dams as compared to Kesses and Kerita Dams. This is due to high competition for DO by macro invertebrates during respiration which only make the more tolerant species survive as the temperature conditions might also not be favourable to less tolerant species. This is in line with Seaman and Kok (1987) who reported that dissolved oxygen (DO) concentration in SWBs varied according to local conditions, mainly temperature, time of the day and season. In the present study, higher DO concentrations were recorded in water bodies at lower temperatures (low altitude areas) than in higher temperatures (high altitude areas). A possible explanation for this is that higher temperatures induce increased biological activity in the water column, with larger organisms requiring more DO for respiration and the smaller microorganisms increasing their demand for DO in order to carry out aerobic biodegradation of deposited organic matter in the water body this results into only more tolerant species thriving as opposed less tolerant ones. This trend was clear in high and low altitude dams as they registered high and low species diversity and richness. It was also observed that higher DO concentrations occurred in sampling months just after heavy down pour and were lowest during dry spell. This phenomenon could be explained by what can be termed the “cascading temperature and standing crop” theory of lentic water bodies according to Seaman and Kok (1987). During the short rains, temperatures are moderate; nutrients enter the water bodies through runoff and streams; due to the favourable temperatures and increased nutrient levels, there is algal bloom resulting into higher algal standing crop with increased DO from the photosynthetic activities of these algae; the high biomass of algae cause the standing crop of macroinvertebrate and zooplankton to increase up to a given tolerant limit; beyond this limit the standing crop of these biological organisms will decrease. The cascading consequences are that during the dry spell the phytoplankton, deplete much of the nutrients while at the same time the macroinvertebrates and large zooplankton population exert increased grazing pressure on the algae, resulting into heightened mortality rates of algae, reduced photosynthetic activity, more demand for DO to support respiratory activity of larger organisms, higher demand for aerobic respiration by microorganisms and therefore, reduced DO and increased biological oxygen demand (BOD) in the water column (Seaman and Kok, 1987; Ngodhe et al., 2013). This could explain the present results as it imply that variation in temperature and DO cause negative or positive growth in macro invertebrates hence high species diversity and richness as was also reported by Sabater (2004).

Principal component analysis (PCA) has been used to differentiate waters of different qualities (Zhang et al., 1992; Brodnjak-voncina et al., 2002) by chemometrics methods used for the classification and comparison of different samples (Massart et al., 1997). Since the vector displacement of the principal components are directly related/proportional to the level/extent of the effect of the variables measured and the stations they correspond to, the largest principle component vector displacement among the stations was deduced to be the most polluted area. In this study, PCA further confirmed the change of species diversity, dominance and richness with the change of water quality parameters in different water bodies. Component 1 and 2 are sufficient to describe the environmental factors (water quality parameters) that affect these water bodies for instance, Kesess and Kerita have a strong positive influence of pH, TN, BOD and DO with component 1 that describes 82.347% of the variation among the stations, this is negative with respect to Mauna and Yenga Dams. The converse is true for temperature which positively affects Mauna and Yenga yet negatively influence Kesses and Kerita with component 1 while component 2 have 14.34% variance (Figure 12). The combination of these two components explains 82.347 + 14.34 = 96.687% of the variation in water quality parameters among the small water bodies. This analysis confirms the impact water quality parameters have on macro invertebrate communities. This concurs with Herrmann (1999) who noted that slight eutrophication due to change in water quality seems to favour increased diversity, however, excess amounts of nutrients resulting in increased primary production and consequently oxygen depletion, probably affecti macroinvertebrate diversity negatively. Harding et al. (1998) also noted similar weak significant correlation results and suggested that high periphyton biomass due to nutrient enrichment and sedimentation in some of the stations that they sampled favoured some taxa such as Chironomids, Snails and Oligochaetes at the expense of Ephemeroptera and Trichoptera. This study noted the decline in diversity of macroinvertebrates, with the low abundance or absence of Ephemeroptera and Trichoptera due to increased nutrient levels because of agricultural and other anthropogenic activities. It can therefore be concluded that variation in species diversity, dominance and richness were as a result of spatio-temporal change of water quality parameters sampled.

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*Review*

# Brick kiln emissions and its environmental impact: A Review

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**Brick manufacturing is the fastest-growing industrial sector in many countries (like china, India, Bangladesh and Pakistan) and among the top three sectors, along with vehicle exhaust and resuspended road dust, contributing to the air pollution and health problems in Dhaka (Bangladesh). The total emissions from the brick manufacturing in the Greater Dhaka region, to produce 3.5 billion bricks per year has been estimated about 23,300 tons of particulate matter having aerodynamic diameter < 2.5 µm ($PM_{2.5}$), 15,500 tons of sulfur dioxide ($SO_2$), 302,000 tons of carbon monoxide (CO), 6,000 tons of black carbon (BC) and 1.8 million tons of carbon dioxide ($CO_2$). Emission of individual air pollutant from brick kilns varied significantly during a firing batch (seven days) and between kilns. Average emission factors per 1,000 bricks were 6.35 to 12.3 kg of CO, 0.52 to 5.9 kg of $SO_2$ and 0.64 to 1.4 kg of particulate matter (PM). Presently sulphur dioxide ($SO_2$), oxides of nitrogen ($NO_x$) and suspended particulate matter (SPM) are the main issue pertaining to air pollution problems in developing countries, where it contributes both to urban pollution and to regional acid depositions. Among man-made sources, coal combustion in stationary sources accounts for 74%, industries 22% and transportation 2% of the total oxides of sulphur ($SO_x$). and it is considered that $SO_2$ is the chief emission in brick production. On an international basis, 75 to 85% of $SO_2$ emissions are the result of fossil fuel burning. It is predictable that just about 93% of the global $SO_2$ emissions are emitted in the northern hemisphere. It has been revealed that biomass is responsible for the emission of both trace and non trace gases such as carbon dioxide ($CO_2$), methane ($CH_4$) and oxides of nitrogen ($NO_x$) from traditional brick industries and lots of toxic fumes containing suspended particulate matters rich in carbon particles and high concentration of CO and $SO_x$ get produced. Studies have shown the average value of particulate matter of size less than ten microns and total suspend particles for the pre-operation time of brick kilns was 0.029 and 0.033 mg/m³, respectively whereas, it reached 0.050 and 0.056 mg/m³, respectively during the brick kiln operation time. Similarly, recent studies on brick kilns in District Budgam of Kashmir valley (India) have shown some major negative impacts on the environment in respect of air quality, human health and vegetation in particular.**

**Key words:** Pollution, emissions, environment, industrialization, transportation, brick kiln, human health, vegetation.

## INTRODUCTION

The literature concerning air pollution with special reference to brick kilns across the globe dates back to the beginning of the nineteenth century. Since the available information in the form of published literature is so enormous, it is not possible to cite all the available literature in the body of present review paper. Hence only important and relevant literature has been cited in the present review paper under the following subheadings:

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(i) Sources of air pollutants,
(ii) Environmental health effects of air pollutants,
(iii) Environmental stress to crop plants due to air pollutants,

## SOURCES OF AIR POLLUTANTS

Sulphur dioxide ($SO_2$) is one of the main products released from the combustion of sulphur containing compounds in most energy fuels having significant environmental concern. The term $SO_x$ is a generic term describing emissions of $SO_2$ and $SO_3$. At low concentrations it is a colourless and odourless gas. On a worldwide scale, anthropogenic emissions stand for a major contribution to the $SO_2$ emitted to the atmosphere (IARC, 1992) and these emissions are just about equal to natural emissions (WHO, 1979). On an international basis, 75 to 85% of $SO_2$ emissions are the result of fossil fuel burning while the rest of the emissions are the outcome of refining and smelting (Friend, 1973). It is predictable that just about 93% of the global $SO_2$ emissions are emitted in the northern hemisphere and the left over 7% are emitted in the southern hemisphere (WHO, 1979). The highest sources of $SO_2$ emissions are from the burning of fossil fuels and smelting sulphide ores (Weil and Sandler, 1997). One more noteworthy cause is petroleum refining (HSDB, 2002). Other less important sources comprise chemical and associated products manufacturing, metal processing, other industrial processes and vehicle emissions (ATSDR, 1998). Brick manufacturing is the fastest-growing industrial sector in Bangladesh and among the top three sectors, along with vehicle exhaust and resuspended road dust, contributing to the air pollution and health problems in Dhaka. The total emissions from the brick manufacturing in the Greater Dhaka region, has been estimated at by Guttikunda et al., 2013, 23,300 tons of $PM_{2.5}$, 15,500 tons of $SO_2$, 302,000 tons of CO, 6,000 tons of BC, and 1.8 million tons of $CO_2$ emissions from the clusters of brick kilns, to produce 3.5 billion bricks per year. Emission of individual air pollutant from brick kilns varied significantly during a firing batch (seven days) and between kilns. Average emission factors per 1,000 bricks were 6.35 to 12.3 kg of CO, 0.52 to 5.9 kg of $SO_2$ and 0.64 to 1.4 kg of PM (Le and Oanh, 2010).

A significant feature of $SO_2$ is that once it is emitted into the atmosphere it can be converted through complex oxidation reactions into fine particulate sulfate and removed from the atmosphere by wet or dry deposition (De, 2012). The emission of $SO_x$ in brick making has received considerable attention (Wilson and Johnson 1975; Amison, 1992; Junge, 1992; Hofer, 1994). Presently, $SO_2$ is the main issue pertaining to air pollution problems in developing countries, where it contributes both to urban pollution and to regional acid depositions (Cofala et al., 2004). Among man-made sources, coal in stationary sources accounts for 74%, industries 22% and transportation 2% of the total $SO_x$ (De, 2012). $SO_2$ is the chief emission in brick production (Junge, 1992). The oxidation of pyrite ($FeS_2$) takes place in a stepwise approach with an initial release of $SO_2$ around 450°C from brick making raw material with an additional increase in temperature and the subsequent emission of sulfates occurs as $SO_2$ (Banerjee et al., 1980; Junge, 1992; Sanders, 1995). But Parsons et al. (1997) opined $SO_2$ can also be released during oxidation of sulfur containing carbonaceous matter at low temperatures. The successive emission of $SO_2$ begins above 750°C and can continue through the firing cycle (Junge, 1992). The residence time of $SO_2$ in the atmosphere ranges from about 2 to 8 days (Katz, 1977), while as Hidy (1994) gives residence times of $SO_2$ in the lower atmospheres of one to three days and HSDB (2002) gives residence times ranging from one to five days.

On an average, a brick kiln producing 800,000 bricks, uses large amounts of rubber to start the burning process and burns a total of eight tons of low quality coal or 20 drums of used vehicle oil, thus releasing many toxic pollutants such as $NO_x$, CO and dioxins (EPA, 2007). In the same year (EPA, 2007) studied the rising number of brick kilns in Peshawar city of Pakistan, which has almost doubled the level of air pollution ($SO_x$, $NO_x$ and volatile organic compounds (VOCs)). A rapid increase in the brick production and the clustering of brick kilns has given rise to environmental concerns throughout the world. Combustion of coal besides other biomass fuels in brick kilns results in the emissions of PM, BC, $SO_2$, $NO_x$ and CO (Maithel et al., 2002). Estimations designate that annual emissions from brick kiln industry were 80 tons of particulate matter, 30 tons of carbon, 7 tons of $NO_x$ and 5 tons of $SO_x$ (Asgher and Singh, 2003).The emission of these pollutants has an adverse effect on the health of brick kiln workers and vegetation around the kilns. In recent years, higher cost and shortage of good quality bituminous coal has resulted in increased use of high-ash, high-sulphur coal, as well as use of industrial wastes and loose biomass fuels in brick kilns. All of these have resulted in new air emission challenges. Good quality agricultural topsoil is mainly used for brick production which leads to the land degradation (Greentech Knowledge Solutions, New Delhi, 2012). Due to the blooming of brick kilns in the Kashmir valley the concentration of $SO_x$, $NO_x$ and PM around brick kilns areas were above the permissible levels during the operational phase of the brick kilns (Fatima, 2011; Hussan et al., 2013). Further, the brick making industries in the Sudan act as a serious agent of deforestation and can be considered important sources of greenhouse gas emission and also toxic fumes containing suspended particulate matters rich in carbon particles and high concentration of CO, $SO_x$ and $NO_x$, as they use huge amount of fuel wood coming from unsustainably managed forest and dung cake for brick burning with the brick kilns of low combustion efficiency. Therefore, brick making industries can be considered as one of the important sources of greenhouse gases (World Bank, 1998; FAO, 1999; Alam, 2006). At the same time long-term brick kiln industrial activity affected the soil characteristics, structure of plant biomass and species diversity. This structural alteration is indicative of adjustment implications for plant communities in anthropogenic ecosystems (Gupta and Narayan, 2010).

$SO_2$ is a prime pollutant which is released directly to the atmosphere from domestic and industrial processes, particularly those using petroleum and coal combustion (Wellburn, 1998; Emberson et al., 2001). $SO_2$ can be oxidized in the atmosphere to form sulphate aerosols that contribute to acid deposition (Holleman, 2001). Thus elevated level of sulphate ions ($SO_4^{2-}$) concentrations in rain water are due to strong $SO_2$ emissions from coal fired thermal power plants (Demirak, 2007). While as it has been predicted that $SO_2$ concentrations from point source emissions are lower than those from area source emissions during the non heating season (Cheng et al., 2006), it has also been discussed that temperature has a significant effect on $SO_2$ concentrations, and humidity and wind speed have insignificant effect (Salam et al., 2008). Most of the brick kiln plants use a low quality coal or other solid waste material and thus results in the production of $SO_x$, $NO_x$, $CO_x$ and PM along with many other organic pollutants due to burning of substandard waste material. Therefore, with a rapid but unrestrained development, emissions from these sources is constantly increasing and unfavorably distressing the environment (Elampari et al., 2010; Hassan et al., 2012). The concentration of $SO_2$ from motor vehicles is very low as compared to stationary sources using solid and liquid fuels (Williams, 2000). Furthermore concentration of $SO_2$ from motor vehicles has been found in higher concentration in winter months followed by summer and monsoon months (Goyal et al., 2006; Emberson et al., 2009), also in Industrial areas (Reddy and Ruj, 2003). But apart from the Industrial and vehicular exhausts ($SO_x$, $NO_x$ and PM), fumes from brick kilns also contribute to the increase in the level of local $O_3$ at surface levels (Pudasainee et al., 2006). It has been revealed that biomass is responsible for the emission of both trace and non trace gases such as $CO_2$, $CH_4$, $N_2O$, $NO_x$ and NO from traditional brick Industries and lots of toxic fumes containing SPM rich in carbon particles and high concentration of CO and $SO_x$ get produced (Alam, 2006). It has also been reported that brick kilns, producing in excess of 350 million bricks are the major and single source of $SO_2$ and PM in the environment of Kathmandu valley; contributing over 60% of the emissions (Maity, 2011). The major removal mechanisms of $SO_2$ from the atmosphere are dry deposition and chemical oxidation (Cheng et al., 2006). It is indicated that almost 10% $SO_2$ removal efficiency could be achieved using water as scrubbing liquid without any additive under certain hydrodynamic conditions (Bandyopadhyay, 2009).

$NO_x$ represents composite atmospheric gases, NO and $NO_2$, which are primarily involved in air pollution. NO is a colourless, odourless gas, but $NO_2$ has reddish-brown colour and pungent suffocating odour (De, 2012). The formation of NO is favored at high temperature, usually attained during much combustion process involving air (1210 to 1763ºC). The second reaction is also favored at temperatures about 1100ºC, but the amount of $NO_2$ formed is usually less than 0.5% of the total $NO_x$ at 1100ºC. It is also formed by photolytic reaction; further man-made sources annually release $5 \times 10^7$ tons of $NO_x$ (De, 2012). The $NO_2$ levels depend mainly on chemical reactions and not on direct emissions (Mayer, 1999). $NO_x$ emissions in brick making mainly originate from the oxidation of nitrogen in the atmosphere by burning (Pauls, 1989; Amison, 1992). Pauls (1989) mentioned that there can be emissions of $NO_x$ during the oxidation of nitrogen containing organic compounds and thus $NO_x$ giving off from the brick kilns has a major role in the formation of ozone and the presence of $NO_x$ is very essential since $NO_2$ can be the only potential source of ozone in the brick kiln areas. Several studies have also shown that the emission of $NO_x$ in brick making has not been found to be significant (Pauls, 1989; Kolkmeier, 1991; Amison, 1992). However, if there is a fractional amount of $NO_x$ present in the troposphere, it receives solar radiation and the $O_3$ is produced (Tang, 2009).

It is considered that coal-fired power plants and vehicles are the nation's largest source of $NO_x$ and is produced in high temperature combustion processes (Memon, 2000; Emberson et al., 2001). $NO_x$ is emitted from a variety of natural and anthropogenic sources (Al-Khalaf, 2006). But its concentrations in the atmospheric surface stratum of rural areas increases by traditional brick kiln industries (Elampari et al., 2010). Due to the improper construction of kilns large amount of fumes is released which may contain gases like CO, $CO_2$ and $NO_x$ and hence brick kilns are acting as a point source of the precursor gases of ozone. The local meteorological factors (clear sky conditions and intense solar flux density) and the activities involved in the brick kilns played a great impact on the observed pattern of $NO_x$. So the mean concentration of $NO_2$ at night was greater than that of day which may be attributed to the photochemical reaction taking place for ozone production during the daytime using $NO_2$ as a fuel (Elampari et al., 2010). NO is by far the most important nitrogen containing species emitted into the atmosphere on a mass basis from human activities involving motor traffic and combustion in power stations, in the home or in industrial processes (Williams 2000; Kumar and Joseph, 2006; Ali and Athar, 2006). $NO_x$ levels were found to be stabilized in residential and industrial zones but increased alarmingly at commercial zones representing higher traffic activities (Goyal et al., 2006). Moreover, $NO_x$ concentration has been found maximum at the time of the evening due to high traffic density of public and commercial vehicles (Jain and Saxena, 2001). $NO_2$ levels were also higher in the post monsoon season followed by winter and pre-monsoon seasons (Goyal et al., 2006).

SPM are finely divided solids or liquids that are dispersed throughout the air and are produced from combustion processes, domestic and industrial activities, as well from natural sources such as volcanoes, dust and forest fires (Emberson et al., 2001). As EPA in 2012, defined, tiny airborne particles or aerosols that are less than 100 micrometers are collectively. SPM in the atmosphere is normally defined as two size classes, $PM_{10}$ (particles with aerodynamic diameter <10 μm) and $PM_{2.5}$ (particles with aerodynamic diameter < 2.5 μm). From all the sources it is estimated that about 800-2000 million tons are being injected into the atmosphere while as statistics concerning man made particulate pollution indicates that fuel combustion from stationary sources, industrial processes and miscellaneous sources contribute about uniformly (1/3rd each) the total particulate emission (200 to 450 million tons/year), in addition, in developed countries like USA, the annual particulate discharge is about $20 \times 10^6$ as well as $5 \times 10^6$ tons of fine particles (De, 2012). SPM can be a local problem close to large sources, but under certain circumstances it can be a local scale pollution issue. The particle size and composition depends upon the source; for instance, mineral dusts start off from mineral oxides and the matter from the earth's crust (UNEP, 2007). SPM is usually divided into two types: primary particles which start off directly from sources and secondary particles produced by the amalgamation with other compounds for instance the photo-oxidation of $NO_x$ to form nitrates (Sharma, 2012). Particulate matter emissions in brick production consist of mineral matter specifically dust entrained in process gases and condensable particulate matter. Condensable particulate matter hypothetically can contain metals that have been volatilized during firing (Brosnan and John, 1998; Brosnan, 2000).

For Dhaka, one of the most polluted cities in Asia, studies show that five months per year, brick kilns are the city's main source of fine particulate pollution, accounting for 38% of total fine particulate mass (Croitoru and Sarraf, 2012). According to a study conducted by the World Bank (1997) in Kathmandu valley, the main contributing sources for total SPM are cement factory (36%), brick kilns (31%), domestic fuel combustion (14%), road resuspension (9%) and vehicle exhaust (3.5%). However, for the $PM_{10}$ concentration, which is of a more apprehension as these particles can enter the respiratory system; contribution of brick kilns was found to be more than other sources (28%) (World Bank, 1997). Studies have shown the average value of particulate matter of size less than 10 microns and total suspend particles for the pre-operation time of brick kilns was 0.029 and 0.033 mg/m³, respectively whereas, it reached 0.050 and 0.056 mg/m³, respectively during the brick kiln operation time, thus concluded that ambient air pollution due to brick kilns in the rural areas is a real problem (Joshi and Dudani, 2008). The concentration of particulate matter in brick kiln areas were found beyond the permissible limits while as, along the distance the concentration goes on decline (Hassan et al., 2012). Moreover, Ismail et al. (2012) has publicized high load of dust with 23.8 to 46.0 g $m^{-2}$ $month^{-1}$ at 50 m distance ahead of brick kilns and heavy metals in the dust samples showed that cadmium (Cd) and chromium (Cr) are added into the environment with a rate of 0.08 and 0.52 mg $m^{-2}$ $month^{-1}$ respectively, resulting in higher pollution prospective near the brick kiln chimneys.

In addition, local traffic is the dominating source of ultra fine particles, while regional and long range transport can have a dominating effect on the fine particulate mass (Kukkonen et al., 2001). Subsequently it was observed that coal combustion is the main source of airborne particles (Xie et al., 2009). The $PM_{10}$ and $PM_{2.5}$ concentrations showed a high increase when compared with total suspended particulate (TSP) concentrations in anthropogenically polluted air (Chung et al., 2003a,b; Chung and Kim, 2008). In addition, particulate mass originates mostly from fine particles and about 88% of $PM_{10}$ mass were from $PM_{2.5}$ (Salam et al., 2008). Among the inorganic compounds, most essential ones are the trace metals, which are emitted by diverse natural and anthropogenic sources such as crustal materials, road dust, construction activities, motor vehicles, coal and oil combustion, incineration and other industrial activities (Watson et al., 2002; Quiterio et al., 2004; Arditsoglou and Samara, 2005; Shah et al., 2006; Shah and Shaheen 2010).

## ENVIRONMENTAL HEALTH EFFECTS OF AIR POLLUTANTS

Emissions from brick kilns is comprised of fine dust particles, hydrocarbons, $SO_x$, $NO_x$, fluoride compounds, CO and small amount of carcinogenic dioxins (Environment Improvement Programme,1995). $SO_2$ is a water soluble, irritant gas, which predominantly affects the upper airways. Infiltration of the air pollutants is larger through mouth inhalation than with nose inhalation and while work working. Sulphuric acid has been classified as a group-1 carcinogen by the International Agency for Research on Cancer (IARC, 1992; Scott, 1998). Acute exposure to $SO_2$ produces instant bronchial constriction, contraction of the airways, amplified pulmonary resistance, increased airway reactivity and changes in metabolism while as chronic exposure consequences in inflammation of the mucosal tissues and increased secretions (WHO, 1979; Amdur, 1978;). Mutilation of lung function and condensed life span in humans has been attributed to long standing exposures to urban air pollution (Costa and Amdur, 1996; Heyder and Takenaka, 1996). Disclosure to sulfur dioxide in the ambient air has been linked with reduced lung function, increased prevalence of respiratory symptoms and diseases, irritation of the eyes, nose and throat and early mortality. Children, the elderly and those previously suffering from respiratory ailments, such as asthmatics, are mostly at risk. Health impacts appear to be linked particularly to concise exposures to ambient concentrations above 1,000 μg/$m^3$ (acute exposures calculated over 10 min) (World Bank Group, 1998). The undesirable effects associated with exposure to $SO_2$ seem inferior with humid conditions (WHO, 1979). Sulphuric acid also binds to the surface of particulates in the air, the minor the particulate the greater the surface area and larger the capability to penetrate the lungs more profoundly (Costa and Amdur, 1996). $SO_2$ has been reported to stay in the lungs for up to one week or more (Balchum et al., 1960a *cf*. WHO, 1979). Once inhaled, $SO_2$ dissolves in the aqueous surfaces of the respiratory system as sulphite and bisulphite, which is immersed into the cells in the respiratory tract and dispersed through the body (Yokoyama et al., 1971; Costa and Amdur, 1996; Wellburn, 1998). Brick kiln industry play important role in the development of respiratory related diseases as has been investigated by Zuskin et al. (1998), there was a significantly higher prevalence of chronic cough (31.8%), chronic phlegm (26.2%), and chest tightness (24.0%) in exposed workers, compared with control workers (20.1, 18.1 and 0%) ($P < 0.05$) and this increased symptom frequency was also documented among non-smokers studied by age and by length of employment, suggesting a work-related effect in brick kilns.

In Bangladesh, it is reported that brick kilns produced $PM_{2.5}$. This fine PM is considering more harmful to human health, because it has the capacity to travel deeper into the respiratory system and cause premature mortality and respiratory ailments (Guttikunda, 2009). From these PM, mainly both elder people and children are suffered more than any ages because on these stages of life our disease prevention mechanisms become weaker (OAQPS Fact Sheet, 1997). American Lung Association (ALA) found in their research that, for the PM in air premature deaths rate increased three times higher than the previous studies. Child mortality rate were also increase for air pollution (ALA, 2006). Recent studies have revealed that a traditional oven emits about 863 pounds of pollutants for each production and burns covering approximately 10,000 bricks (TCEQ, 2002). A health survey clearly showed that people who are living near brick kilns are more likely to suffer from illnesses caused by kilns pollution, comparing those who are living in areas without the kilns. School children nearby brick kilns were had the worse condition of health and they were suffered for higher prevalence of upper respiratory tract infections like pharyngitis and tonsillitis (Joshi and Dudani, 2008).

Studies show that work related dust exposure is a risk factor for acute and chronic respiratory irritation, inflammation and cardiovascular diseases (Koskela et al., 2005). It is also reported that elevated amounts of CO, which is formed in brick kilns due to poor kiln design that consequences in incomplete combustion of coal, could also cause undesirable health effects on central nervous system and eventually resulted in symptoms of headache, nausea, exertion and shortness of breath (Seinfeld and Pandis, 1998; Zuskin et al., 1998; Maynard and Waller, 1999). Plentiful epidemiological studies have exposed a correlation between prominent levels of airborne particulates and amplified rate of morbidity and mortality (Pope, 2000; Shah, 2009). Likewise, epidemiological studies done with respect to the worsening ambient air quality at different places around the world have revealed the evidence of an increase in the rate of bronchitis, asthma, decreased lung function, pharyngitis, cough, eye irritation, fibrosis, emphysema, allergic rhinitis and low birth weight (Pope and Dockery, 1992; Schwartz, 1996; Bobak, 2000; Donaldson, 2001; Pope et al., 2002; Callen et al., 2009). The airborne particulates and associated trace metals have been related to both acute and chronic adverse health effects which mostly consist of respiratory diseases, lung cancer, heart diseases and damage to other organs (Prieditis and Adamson, 2002; Magas et al., 2007; Wild et al., 2009). Lots of studies conducted in the coal mining areas showed higher ambient particulate concentrations (Ghose and Majee, 2002; Sinha and Sreekesh, 2002; Suman et al., 2007) and also reported that CO, $NO_x$ and $SO_x$ causes dizziness, headache, fatigue, and impaired judgment, lung irritation, bronchitis, pneumonia, asthma, respiratory infections, pulmonary edema and emphysema. They also influence the functioning of brain and heart. Further, analyzed particulate matter combined with sulphur oxides is more detrimental than either of them separately, while as ground level ozone in photochemical smog causes chest constriction and irritation of the mucous membrane. Some of the problems linked with pollution of the atmospheric air as shortage of oxygen for animal respiration, poor visibility, irritation of the eyes, increase cases of upper respiratory infections and unpleasant odours (Mishra, 2003). Further, increased prevalence of respiratory complaints like cough, sputum, wheezing and dyspnea among exposed workers of cement, tile and ceramic factories compared to control was statistically significant (Myers et al., 1989; Mustajbegovic et al., 2003; Mwaiselage, et al., 2005; Kakooei and Marioryad, 2005; Ugheoke et al., 2006; Halvani et al., 2008; Dehghan et al., 2009; Aziz et al., 2010). It has been observed that 78% of the workers are not using Personal Protective Equipment (PPE) which leads to the respiratory symptoms among the workers (Singh et al., 2000, 2009, 2011). While as, the most common respiratory symptoms reported by farm workers (wheeze, dyspnea and cough) which were relatively unfocused and can be associated with several occupational respiratory disorders (Linaker and Smedley, 2002). Studies revealed that the vehicle emissions such as BC, carbonaceous gases and ultra fine particulate matter ($PM_{1.0}$) are chief environmental grounds of cardiovascular mortality and morbidity in the United States (Grahame and Schlesinger, 2009).

## ENVIRONMENTAL STRESS TO CROP PLANTS DUE TO AIR POLLUTANTS

Plants are main indispensable parts of ecosystems and their sensitivity to air pollution is more considerable than standards of air pollution (Thomas, 1991). Air pollution has become a serious environmental stress to crop plants due to increasing industrialization and urbanization during the last few decades (Rajput and Agrawal, 2004). Among plants, conifers become visible to be more sensitive to the effect of sulfur dioxide (Ozolincius et al., 2005). Plant species vary in their sensitivity level to pollutants (Jacobson and Hill, 1970). Diverse changes induced by different air pollutants in plants with respect to morphological, anatomical and physiological characteristics have been investigated (Rao,1981; Pawar and Dubey, 1983).The most frequent injury indicator produced by $SO_2$ on broad leaved species is tan to dark brown interveinal bifacial necrosis (Panwar, 1982). The most disperse and injurious pollutants in industrial areas are $SO_2$, $NO_x$, CO, tropospheric ozone ($O_3$) and heavy metals, as well as suspended particulate matter (Assadi et al., 2011). A range of air pollutants is recognized as phytotoxic agents and phytotoxicity of $SO_2$ has been documented for about a century (Godzik and Sienkiewicz, 1990), sound effects of ozone for more than 30 years (Miller, 1983), acidic precipitation for more or less 20 years (Likens et al., 1979) and effects of prominent levels of nitrogen compounds, $NO_x$ and ammonia in the last decade (Nihlgard, 1985). Significance of other pollutants such as peroxy acetyl nitrate (PAN) (Su et al., 2006), fluorides (Maclean, 1981) or heavy metals has also been documented (Unsworth and Harrison, 1985). Plants in the immediate vicinity of emissions sources are more vulnerable. It has been revealed that the most sensitive species of plants start on to show visible signs of damage at concentrations of about 1,850 $\mu g/m^3$ for 1 h, 500 µg/m3 for 8 h, and 40 $\mu g/m^3$ for the maturing season (*cf.* NAPAP 1990). It is possible that over the long term, sulfur input to soils will affect crop yields (OECD 1981; NAPAP 1990). Sulfur dioxide shows negative effects in terms of foliar injury, physiological and biochemical alterations on vegetation (Kainulainen et al., 1995) and chlorophyll content (both chlorophyll 'a' and chlorophyll 'b') decreasing with the increase in $SO_2$ concentration (Prakesh et al., 2002).

Also phaeophytin, carotenoids, carbohydrates, proteins and phenolic content decreased on exposure to sulfur dioxide (Ganai et al., 2007a,b; Balkhi et al., 2009, Jan et al., 2010; Irshad et al., 2011 ) and short term treatment of $SO_2$ damaged pigment system-II (PSII), decreased the fluidity of thylakoid membrane and affected the process of electron transport (Liu et al., 2007). Impact of brick kiln emissions on *Malva sylvestris* in respect to biochemical parameters (photosynthetic pigments, starch, carbohydrates) showed a negative trend as compared to control (Ganai et al., 2010) and similarly Pawar et al*.* (2010) showed that air pollutant reduces the photosynthetic activity of Kachnar leaves and there was a significant increase in the amount of phenol in the Kachnar leaves associated with the degree of injury of the leaves. The particulates and gaseous pollutants, alone and in combination can cause grave setbacks to the overall physiology of plants (Ashenden and Williams, 1980; Mejstrik, 1980; Anda, 1986). Of all plant parts, the leaf is the most sensitive part to the air pollutants (Singh, 1990).

Acid deposition can smash up forests and crops by acidification of soil and it also causes lakes and stream acidification (USEPA, 2007). The gaseous $SO_2$ can cause direct injury to crops and forests by entering the leaves through the stomata and deposition to external surfaces, leading to negative effects on the growth. Yield of the plant and acute visible injury to plants is caused by absorption of high concentrations of $SO_2$ over a relatively short time; in addition, foliar symptoms are generally interveinal chlorosis (whitened areas) which run through to the edges of the leaves thus, the fully expanded leaves are more sensitive to acute $SO_2$ injury, as compared to the very youngest and oldest leaves (Heather, 2003). The crop species that are usually considered susceptible to $SO_2$ are alfalfa, barley, wheat, clover, oats, pumpkin, radish, spinach, lettuce, squash, beans and tobacco and resistant crop species include asparagus, cabbage, corn, onion and potato (Thomas and Hendricks, 1956; Kondo and Sugahara, 1978). The adverse effects of air pollution on vegetation have been well reviewed in terms of foliar injury, physiological as well as yield characteristics (Singh and Rao, 1981; Murray and Wilson, 1988; Wilson and Murray, 1990; Agrawal et al., 2003; Agrawal and Deepak 2003; Rajput and Agrawal, 2005; Agrawal, 2005; Maggs et al., 1995; Shukla et al., 1990; Agrawal et al., 2003). Chauhan and Joshi (2010) opined that gaseous ($NO_x$ and $SO_x$) and particulate pollutants such as SPM and respirable suspended particulate matter (RSPM) have detrimental effects on wheat and mustard crops and concluded that the total chlorophyll, ascorbic acid and carotenoids contents decreased significantly in response to air pollutants. Pollutants have been shown to reduce the synthesis of chlorophyll enhancing its degradation. Consequently, it is very clear that urban and industrial air pollution has become a serious threat to agricultural production grown adjacent to urban and industrial areas (Sandelius et al., 1995; Agrawal et al., 2003). Chlorophyll content is vital for the photosynthetic activity and Diminution in chlorophyll content used as an indicator of air pollution (Pawar and Dubey, 1985; Gilbert, 1968). Photosynthetic pigments are quite responsive to air pollutants and their sensitivity may decide the response of plants to pollutants (Chauhan and Joshi, 2010). Constant application of cement dust clogs the stomata, thus interfering with gaseous exchange (Lerman (1972). Carotenoids guard from photoxidation damage; hence, their decreases have serious outcomes on chlorophyll pigments (Sifermann, 1987). Joshi and Swami (2007) also reported a significant reduction in carotenoid content of diverse plants grown at polluted sites. The physiological condition of plants is very well indicated by their pigment content (Petkovsek et al., 2008). Ascorbic acid, a natural antioxidant in plants, has been revealed to play a vital role in pollution tolerance (Chen et al., 1990). Significant reductions in yield have also been observed as a result of $SO_2$ pollution in many cereals and pulses (Thomas, 1961; Singh and Rao, 1982). Ozone, $SO_2$ and $NO_2$ separately and in the mixture are known to reduce the yield of many crop plants (Heggesbad and Lesser, 1990; Renaurd et al., 1997; Agrwal et al., 2006) and the yield losses often have been ascribed to reductions in photosynthetic activity and assimilate supplies to hold up reproductive development and seed growth (Kurpa and Kickert, 1989; Agrawal et al., 2003; Agrawal, 2005)

It has been studied that $NO_x$ or at least a combination of $SO_x$ and $NO_x$ is largely responsible for the lichen decline (Loppi and Corsini, 2003; Hussan et al., 2013). Furthermore, $NO_2$ generally affects the leaves and seedlings and its sound effects diminish with increasing age of the plant and tissue (Gheorghe and Barbu, 2011). Further, conifers are found to be more sensitive to this gas throughout spring and summer than in winter. Older needles of conifers are more susceptible to the gas ($NO_2$) than young ones. The gas causes development of crystalloid structures in the stroma of chloroplasts and puffiness of the thylakoid membrane. Consequently, the photosynthetic activity of the plant is reduced**.** The main route of entry of $NO_x$ into plant leaves is through the stomata, the gas then dissolves in leaf cells, giving rise to nitrite ions ($NO_2^-$ ) which are lethal at prominent concentrations, and nitrate ions ($NO_3^-$ ) that enter into nitrogen metabolism like the one absorbed through the roots (Zeiger and Taiz, 2006). $NO_x$ at elevated concentrations in the atmosphere can drastically reduce the growth of the plant particularly under elevated soil nitrogen surroundings. However, $NO_x$ can boost the nitrogen content of the plants and arouse development, when soil nitrogen is limiting and the concentration in the air is moderate. Consequently, exposure to excessive concentrations of $NO_x$ in a relatively short time, will basis abnormal symptoms (Zeiger and Taiz, 2006) and visible foliar injury to the plant in the form of patches of chlorosis and necrosis of the leaves (Ahmad, 2010). Exposing the plant to lesser concentrations of $NO_x$ for a longer period not often causes noticeable injury other than having an effect on growth by suppressing the rate of photosynthesis. NOx in mixture with other pollutants in particular $SO_2$, can cause more harm to vegetation than likely expected from the effects of the individual pollutants depending upon the environmental conditions (Emberson et al., 2001). As the $NO_x$ is the precursor of ozone formation in troposphere and tropospheric ozone ($O_3$) is an important phytotoxic air pollutant. Even though ozone has a significant role in defending the biosphere by absorbing detrimental ultraviolet radiation in the upper stratosphere but in the troposphere it is designated as a phytotoxic air pollutant (Khan and Soja, 2003). The sound damaging effects of photochemical oxidant mixtures on plants were first documented in the late 1940s (Middleton et al., 1950). Ozone is an important part of the air pollution climate in urban and industrialized areas of the world. Its effects are not limited to a small area, because Ozone ($O_3$) precursor's travels lengthy distances in the atmosphere depending upon the wind speed and direction, with higher concentrations often found in rural areas. Ozone pollution is recognized to have significant effects on agricultural production in North America, Western Europe and many other countries of the world (Wang et al., 2005; Zeiger and Taiz, 2006). Ozone concentrations in Northern hemisphere and especially those in developing countries are expected to rise from mean 10ppm to 20ppm by the end of the 21st century due to the increase in its precursor emissions ($NO_x$ and volatile hydrocarbons), being associated with the rise in the number of motor vehicles and industrialization wide-reaching (Wahid, 2006). Ozone is a very much reactive material and before inflowing the stomata can injure the receptors of the guard cells next to the stomata, which are then incapable to respond to environmental signals (Calatayud et al., 2002), within the leaf apoplast it reacts with water to form free radicals like hydro peroxide and superoxide's, which reacts with intercellular fluid in the cell wall and alters the mesophyll cells just within the epidermis, being the main course of carbon dioxide from the stomata to the cells accountable for photosynthesis (Calatayud et al., 2002; Zeiger and Taiz, 2006).

Various gaseous and particulate pollutants emanating from brick kilns show negative impact on the adjacent vegetation. The relative densities of diverse herbs decline in the vicinity of brick kiln as compared to control (Sarkar and Kundu, 1996, *cf* Fatima, 2011). Suspended Particulate Matter (SPM) has an effect on plants in an ample range of ways, depending upon the composition of the particles and is recognized to have direct or indirect effects on agricultural plants. Dust particles are of loca-lized significance near brick kilns, roads, quarries, cement works and other industrial areas (Zeiger and Taiz, 2006). Aside from screening out sunlight in the atmosphere, the undeviating impact of the dust on leaves reduces radiation to chloroplasts and stomatal conductance and can affect control of water loss by physically preventing stomata closure (Zeiger and Taiz, 2006). The direct impact of particles containing contaminants for instance heavy metals can also cause phytotoxicity (Erickson, 1979). Accumulation of particulates on the surface of the plants can in due course alter plant vulnerability to pathogens and pests (Emberson et al., 2001) and the exposure to dust pollution stress provoked significant reductions in photosynthesis in most plants. Thus, may alter plant growth and production, without physical damage to the plant (Kumar and Thambavani, 2012). It is also the fact plants provide a vast leaf area for impingement, assimilation and accumulation of air pollutants diminish the pollutant level in the air environment (Warren, 1973; Shannigrahi et al., 2004), thus can be used as bioindicator of air pollution (Tripathi and Gautam, 2007; Lalitha et al., 2013).

Recent studies on brick kilns in District Budgam have shown some major negative impacts on the environment in respect of air quality, human health and vegetation in particular. Air quality status was turned into severe pollution during the operation phase of brick kilns and community people (including school children) were exposed to emissions from brick kilns which lead them to ailments of respiratory problems and results have also shown the negative impact of brick kiln emissions on biochemical parameters like chlorophyll, phaeophytin, carotenoids, carbohydrate, proteins and lipids of the vegetable species namely *Brassica oleracea*, *Phaseolus vulgaris* L. and *Solanum melongena* L. (Skinder, 2013).

## CONCLUSION

It becomes clear that brick kiln emissions, urbanization and transportation are playing the leading role in deteriorating the environment in respect of air pollution, human health problems and decrease of crop production. This will also lead to global warming. Thus, concluded that ambient air pollution due to brick kilns in the rural areas is a real problem to human health and vegetation.

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*Full Length Research Paper*

# Diel variations in limnological characteristics of Omkareshwar reservoir of Narmada river, India

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**The present study was carried out to ascertain the magnitude of seasonal diel variations in physicochemical and biological variants with reference to phytoplankton, zooplankton and primary productivity at newly formed Omkareshwar reservoir on the river Narmada for the year 2012. Diel variations in physicochemical parameters such as temperatures, pH, transparency, total alkalinity, total hardness, chloride content, dissolved oxygen, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were observed between 1100 and 0700 h. No phytoplanktonic diel variations have been observed, but zooplanktons were well known for their diel variations as they can actively swim towards most suitable environmental niche in the river. The result shows the oligotrophic nature of this reservoir. Maximum value of total phytoplankton (271.97 Org/L) was observed around 1100 h in summer but the highest value of total zooplankton (930.78 Org/L) was recorded at 2300 h in summer season. Maximum value of net primary productivity (600 g C/m$^3$ /3 h) was noticed at 1100 h in summer season. The suitable correlation coefficients were calculated for 15 pairs of variables and correlation matrices were then established seasonally. Net primary productivity (NPP) depicted a positive correlation with dissolved oxygen and phytoplanktonic productivity (r = + 0.577 and r = + 0.459), respectively.**

**Key words:** Biochemical oxygen demand (BOD), chemical oxygen demand (COD), diel, zooplankton, phytoplankton.

## INTRODUCTION

River plays a major role in assimilating or carrying Industrial and municipal waste water, manure discharge and run off which are responsible for river pollution (Choudhary et al., 1991; Toman, 2009). In India, it is important to study the status of pollution of the rivers in relation to various anthropogenic activities as river water has been used as drinking water, for mankind (Suther et al., 2010). River is vital and vulnerable freshwater ecosystems that are critical for the sustenance of all life. The physicochemical properties affect the nutrient status of water body hence trophic status depends on rate of energy flow which may be assessed by estimating primary productivity (Dudani et al., 1987; Zambave et al., 2004; Iqbal et al., 2004). The study of diel cycle is important for a number of obvious reasons. Diurnal fluctuations in these parameters adversely affect the population of an aquatic

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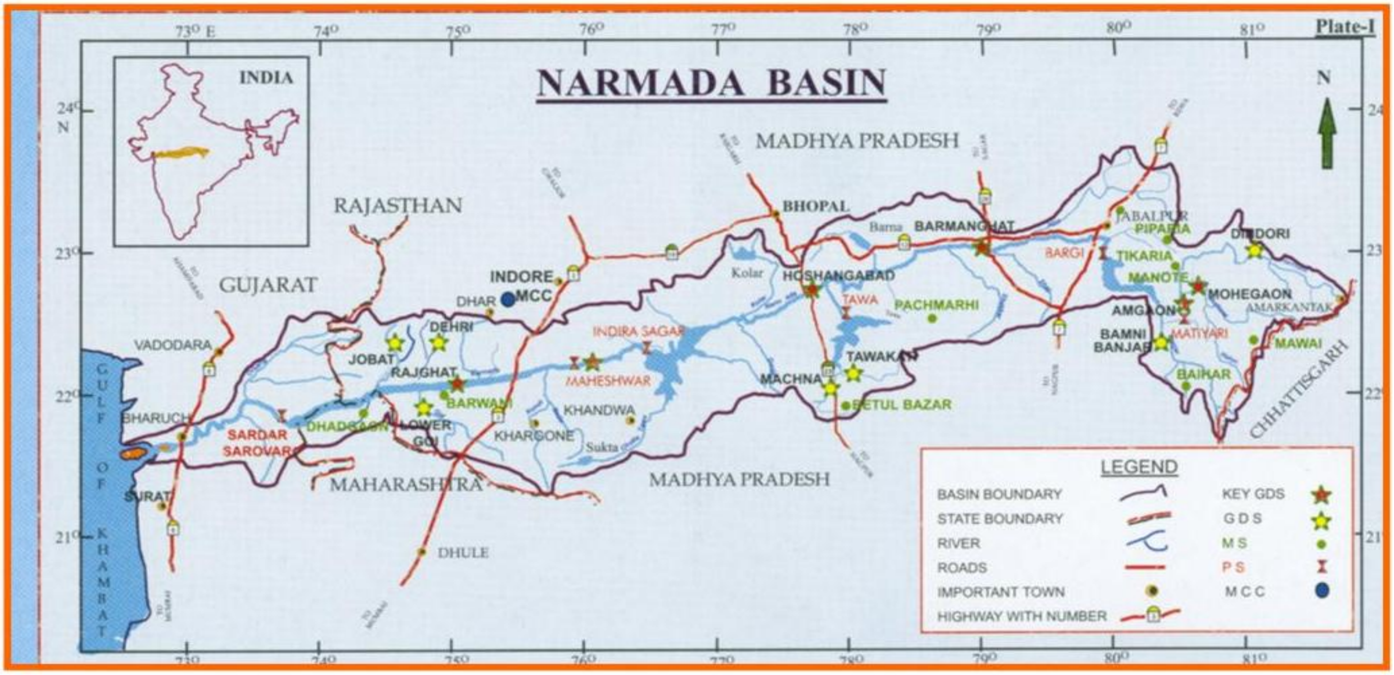


**Figure 1.** The map showing the Omkareshwar reservoir of Narmada river (India).

ecosystem. Practically the entire wheel of life, represented by a vast array of the number of organisms is powered exclusively by the solar energy that is incorporated by the primary producers during day time. Correlated with this rhythm in light intensity are also the rhythms of temperature and humidity and of the tidal cycles due to the effect of the gravitational pull and its modalities due to planetary movements (Schevt et al., 1997). Environmental conditions may change rather dramatically within aquatic ecosystem during a 24 h period. Solar radiation varies from high intensities at mid-day to darkness. Surface temperature and concentrations of dissolved gases may also fluctuate between extremes of day and night, especially in shallow, littoral areas (Wetzel, 1979; Abowei (2010); Singh et al (2010); and Sipkoska-Gastarova et al (2010).

The planktons form the basic link of food chain for all aquatic animals and thus play a pivotal role in fisheries. The direct and indirect alterations in physicochemical parameters of water affect the survival of primary productivity and growth of planktons (Shastri et al., 2000; Gang et al., 2006). Factors which are known to influence the vertical migrations of planktons on diel basis are cellular periodicity that is independent of light; that is, circadian rhythm and the nutrient depletion, presence of anoxic water, under water light regime and temperature or density gradients. The present investigations revealed that by and large the phytoplankton did not show any clear diurnal movement and remain concentrated at the surface or near surface zone. The observed irregular diel migration may be the result of passive movement of phytoplankton by turbulence and water movements due to wind action. Temperature of the water also has been considered as determining factor for the seasonal distribution of the fauna and flora. The phytoplankton was found to play the main role in determining the pattern of fluctuations in the yield of total plankton (Pant et al., 1983; Kamat and Sima, 2000). In this investigation an attempt has been made to corroborate the interrelationships of some physicochemical features of reservoir with the primary productivity and health of phyto-planktons.

## MATERIALS AND METHODS

Narmada river is the fifth largest river of India, which is known as the 'Life Line' of Madhya Pradesh (India). It originates from Amarkantak in Madhya Pradesh. The Narmada Valley Development project is the single largest river development project in India, which involves the construction of more than 3000 large and small dams. Omkareshwar is one of the largest dam which has been developed on the river Narmada and it is situated at a distance of about 4 km from famous Mandhata Island (Figures 1 and 2).

Water samples were taken after every four hours at 1100, 1500, 1900, 2300, 0300 and 0700 h in one whole day for diel study. The water samples were analysed, and several physicochemical parameters such as temperature, pH, alkalinity, transparency, total hardness, total dissolved solids, chloride content, dissolved oxygen, biochemical oxygen demand (BOD), chemical oxygen demand (COD) were analyzed (NEERI, 1986; APHA et al, 2001). The chemicals used for analysis were all of analytical R. grade. Primary productivity in terms of net primary productivity (NPP), Gross primary productivity (GPP) and respiration was estimated by using light and dark bottle method (Sharma and Savang, 2004). Quantitative studies of the planktonic population (phytoplankton and zooplankton) were made as per the standard methodology

**Figure 2.** The exact location of Omkareshwar reservoir, India.

(Sardana et al., 1980; Sharma and Bhardwaj, 1999; Patil and Patil, 2010). Correlation matrices of different physicochemical and biological parameters for three seasons were incorporated with the values of significance (Tables 1, 2 and 3).

## RESULTS AND DISCUSSION

Temperature, being a key abiotic factor in aquatic ecosystem has wide effect on biodiversity of planktons with respect to their growth and other physiological processes. In the present study diurnal variation in the air temperature ranged between 28.50 to 33.50, 26.50 to 30.70 and 22.41 to 24.00°C during summer, monsoon and winter periods, respectively and the diurnal variation in the water temperature ranged between 24.60 to 27.63, 25.20 to 28.70 and 21.23 to 22.10°C during summer, monsoon and winter periods, respectively. The values of temperature gradually increased from 0700 to 1500 h and thereafter their values slightly decreased till 0300 h. Maximum value of temperature was recorded in summer at 1500 h while minimum temperature was found to be at 0700 h. Air and water temperature revealed a definite diel trend over the study period and changes appear to have been brought about by several factors in addition to diel and seasonal changes in solar irradiance. Although, there is little variation in water than in air, temperature is, nevertheless, a major and critical limiting factor for biotic components because most of the aquatic organisms often have a narrow thermal tolerance (Shankar and Sangu, 1986; Mudgal et al., 2009) (Figures 3 and 4). A significant positive correlation was found between air and water temperature ($r = + 0.956$) at significance level of 0.01.

Water transparency is an important limiting factor in the growth and distribution of flora and fauna. Diurnal variation in the transparency ranged between 0.00 to 98.00, 0.00 to 64.00 and 0.00 to 116.00 cm. during summer, monsoon and winter periods, respectively. The Secchi transparency gradually increased from 0700 to 1500 h thereafter it was not observed from 1900 to 0300 h. Maximum transparency (116.00 cm) was observed at 1500 h during winter. Although, in the present study the steady rise in visibility was noticed from 0600 h onwards but decline was reported due to the change in the water surface conditions or occasionally even by planktonic blooms. The transparency increasing from morning to evening has an indirect relationship with nutrients and was chiefly affected by the algal growth. Secchi transparency showed an inverse correlation with a number of physicochemical parameters in diel variations (Figure 5).

pH is numerical expression that indicates the degree to which water is acidic or alkaline. All values were within the permissible limit. pH is known for exerting its influence on the occurrence, distribution and growth of planktons. The high pH value of water was associated with greater photosynthetic activity which resulted in utili-zation of $CO_2$ from bicarbonates and formation of carbo-nates (Baijot et al., 1994). Diel variation in pH fluctuated between 8.10 to 8.40, 8.13 to 8.35 and 8.24 to 8.30 during summer, monsoon and winter periods, respec-tively. The values of pH gradually increased from 0700 to 1500 h, thereafter slightly decreased till 0300 h. Its maxi-mum value (8.40) was observed at 1100 h while mini-mum (8.10) was noticed at 0300 h in summer season. In the present study the pH values showed a definite diurnal trend of daytime increase in reservoir. The rise in pH during daytime indicated high rate of photosynthesis, although the range of fluctuation was usually small (Figure 6).

Total alkalinity of water is due to the presence of mineral salts present in it. It was primarily caused by the carbonate and bicarbonate ions. High alkalinity can be attributed to the rise in temperature which also coincides with the concentration of nutrients and bicarbonates in particular. It has also been observed that relatively higher values of alkalinity were conducive for the growth of

**Table 1.** Correlation matrix of different physicochemical and biological parameters of winter season.

| Parameter | Air temperature | Water temperature | Transparency | pH | Dissolved oxygen | BOD | COD | Total alkalinity | Total hardness | Chloride | Total solids | Total phytoplanktonic productivity | Total zooplktonic productivity | Gross primary productivity | Net primary productivity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Air temperature | 0.000 | | | | | | | | | | | | | | |
| Water temperature | 0.901 | 0.000 | | | | | | | | | | | | | |
| Transparency | -0.663 | -0.756 | 0.000 | | | | | | | | | | | | |
| pH | 0.802 | 0.474 | -0.268 | 0.000 | | | | | | | | | | | |
| DO | -0.033 | -0.444 | 0.193 | 0.481 | 0.000 | | | | | | | | | | |
| BOD | 0.682 | 0.913 | -0.677 | 0.187 | -0.708 | 0.000 | | | | | | | | | |
| COD | 0.828 | 0.948 | -0.740 | 0.418 | -0.496 | 0.889 | 0.000 | | | | | | | | |
| Total alkalinity | 0.692 | 0.931 | -0.687 | 0.172 | -0.727 | 0.986 | 0.929 | 0.000 | | | | | | | |
| Total hardness | 0.874 | 0.991 | -0.830 | 0.426 | -0.445 | 0.910 | 0.960 | 0.933 | 0.000 | | | | | | |
| Chloride | 0.742 | 0.918 | -0.651 | 0.234 | -0.575 | 0.823 | 0.891 | 0.896 | 0.914 | 0.000 | | | | | |
| TDS | 0.910 | 0.990 | -0.710 | 0.505 | -0.421 | 0.870 | 0.960 | 0.908 | 0.977 | 0.939 | 0.000 | | | | |
| Total phy | -0.023 | -0.387 | 0.209 | 0.503 | 0.830 | -0.483 | -0.439 | -0.584 | -0.404 | -0.686 | -0.417 | 0.000 | | | |
| Total zoo | 0.549 | 0.231 | -0.252 | 0.845 | 0.562 | 0.085 | 0.196 | 0.000 | 0.213 | -0.135 | 0.206 | 0.793 | 0.000 | | |
| GPP | -0.760 | -0.814 | 0.987 | -0.383 | 0.143 | -0.687 | -0.769 | -0.700 | -0.871 | -0.704 | -0.776 | 0.185 | -0.305 | 0.000 | |
| NPP | -0.638 | -0.692 | 0.989 | -0.293 | 0.075 | -0.593 | -0.649 | -0.592 | -0.767 | -0.565 | -0.638 | 0.100 | -0.309 | 0.980 | 0.000 |

*Value above 0.51 showing significant at 0.01 level. Value between 0.51 and 0.4 showing significant at 0.05 level.

planktons. High value of total hardness indicated the greater productivity and surge in eutrophication of water body. Hard and alkaline water may be attributed to high planktonic growth to some extent (Joshi et al., 1991; Sujitha et al., 2011) (Figures 7 and 8).

Total dissolved solids (TDS) are suitable parameter in describing the density of chemicals and as a general measure of edaphic relationship that contributes to the productivity of water (Raja et al., 2008). TDS mainly consists of inorganic salts such as carbonates, chlorides, sulphates, phosphates and nitrates of minerals and small amount of organic matter. TDS was found to be the highest 562.00 $mgL^{-1}$ at 1900 h in monsoon season, its highest value was found to be due to loss of water as a result of rising temperature and concentration of salts present in water (Figure 9).

The content of chloride gave a concrete idea of organic matter and presence of nitrates in reservoir. Its content has been reported between 20.87 to 27.99, 22.51 to 26.99 and 18.11 to 21.99 $mgL^{-1}$ during summer, monsoon and winter periods, respectively. Its contents were gradually increased from 1100 to 2300 h; thereafter its values started declining till 0700 h. A maximum of chloride (27.99 $mgL^{-1}$) was recorded at 2300 h in summer. An increase in chloride from 0300 to 1500 h may be ascribed due to the discharge of oils and other harmful substances (Prasad and Patil, 2008) (Figure 10). Dissolved oxygen (DO) is of paramount importance in the study of aquatic status of a reservoir. Oxygen content is indispensible for many organisms and also affects the solubility and availability of many nutrients which has direct influence on primary productivity. The diel varia-

**Table 2.** Correlation matrix of different physicochemical and biological parameters of summer seasons.

| Parameter | Air temperature | Water temperature | Transparency | pH | Dissolved oxygen | BOD | COD | Total alkalinity | Total hardness | Chloride | Total solids | Total phytoplanktonic productivity | Total zooplktonic productivity | Gross primary productivity (GPP) | Net primary productivity (NPP) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Air temperature | 0.000 | | | | | | | | | | | | | | |
| Water temperature | 0.588 | 0.000 | | | | | | | | | | | | | |
| Transparenc | 0.525 | 0.777 | 0.000 | | | | | | | | | | | | |
| pH | 0.682 | 0.635 | 0.332 | 0.000 | | | | | | | | | | | |
| DO | 0.855 | 0.585 | 0.513 | 0.404 | 0.000 | | | | | | | | | | |
| BOD | -0.744 | -0.832 | -0.777 | -0.619 | -0.516 | 0.000 | | | | | | | | | |
| COD | 0.799 | 0.804 | 0.648 | 0.845 | 0.503 | -0.940 | 0.000 | | | | | | | | |
| Total alkalinity | -0.588 | -0.771 | -0.783 | -0.633 | -0.286 | 0.952 | -0.918 | 0.000 | | | | | | | |
| Total hardness | -0.696 | -0.805 | -0.707 | -0.687 | -0.405 | 0.985 | -0.964 | 0.972 | 0.000 | | | | | | |
| Chloride | -0.599 | -0.802 | -0.873 | -0.572 | -0.359 | 0.951 | -0.885 | 0.987 | 0.946 | 0.000 | | | | | |
| TDS | -0.480 | -0.508 | -0.608 | -0.661 | -0.052 | 0.779 | -0.828 | 0.914 | 0.843 | 0.871 | 0.000 | | | | |
| Total phy | 0.760 | 0.679 | 0.255 | 0.935 | 0.557 | -0.650 | 0.836 | -0.564 | -0.692 | -0.502 | -0.486 | 0.000 | | | |
| Total zoo | 0.318 | 0.064 | -0.303 | 0.452 | 0.458 | 0.228 | 0.023 | 0.348 | 0.224 | 0.362 | 0.338 | 0.521 | 0.000 | | |
| GPP | 0.499 | 0.885 | 0.758 | 0.270 | 0.577 | -0.809 | 0.635 | -0.683 | -0.735 | -0.737 | -0.328 | 0.414 | -0.211 | 0.000 | |
| NPP | 0.472 | 0.901 | 0.734 | 0.327 | 0.500 | -0.836 | 0.680 | -0.734 | -0.783 | -0.770 | -0.396 | 0.459 | -0.236 | 0.991 | 0.000 |

*Value above 0.51 showing significant at 0.01 level. *Value between 0.51 and 0.4 showing significant at 0.05 level.

tion in dissolved oxygen ranged between 7.50 to 8.40, 6.90 to 8.40 and 8.00 to 8.90 $mgL^{-1}$ during summer, monsoon and winter periods, respectively. Diel fluctuations in DO showed a gradual increase from 0700 to 1500 h there after it was found to be declining till 0300 h. In the present study maximum DO (8.90 $mgL^{-1)}$ was observed at 1500 h during winter season, while minimum (6.90 $mgL^{-1)}$ was recorded at 0700 h in monsoon . High DO at 1500 h may be due to the high photosynthetic activity during day time. DO finds its way into the aquatic system either by passive non-biological diffusion at water surface or is liberated by autotrophs as a byproduct of photosynthesis and gets dissolved in water depending on its partial pressure. A marked diurnal pulse of dissolved oxygen content is evident in water depending on the extent of autotrophic production and its modalities under influence of various environmental factors (Figure 11).

Dissolved oxygen content and the range of its diel variation had an inverse relationship with total carbon dioxide. The water was under saturated with oxygen during most of the observations and the percent dissolved oxygen concentration behaved diurnally in the same way as the dissolved oxygen values expecting slight modalities during winter probably due to increased solubility. DO was positively correlated with pH (r = +0.837 and r = +0.481) during monsoon and winter seasons respectively and negatively correlated with temperature (r = -0.560). Such correlation supports the role of photosynthesis in governing above parameters.

**Table 3.** Correlation matrix of different physicochemical and biological parameters of monsoon season.

| Parameter | Air temperature | Water temperature | Transparency | pH | Dissolved oxygen | BOD | COD | Total alkalinity | Total hardness | Chloride | Total solids | Total phytoplanktonic productivity | Total zooplktonic productivity | Gross primary productivity | Net primary productivity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Air temperature | 0.956 | 0.000 | | | | | | | | | | | | | |
| Water temperature | 0.517 | 0.324 | 0.000 | | | | | | | | | | | | |
| Transparency | -0.048 | 0.131 | -0.560 | 0.000 | | | | | | | | | | | |
| pH | 0.501 | 0.615 | -0.160 | 0.837 | 0.000 | | | | | | | | | | |
| DO | -0.635 | -0.475 | -0.879 | 0.743 | 0.286 | 0.000 | | | | | | | | | |
| BOD | -0.701 | -0.608 | -0.804 | 0.638 | 0.174 | 0.968 | 0.000 | | | | | | | | |
| COD | -0.649 | -0.535 | -0.786 | 0.740 | 0.291 | 0.969 | 0.979 | 0.000 | | | | | | | |
| Total alkalinity | -0.708 | -0.636 | -0.710 | 0.642 | 0.184 | 0.939 | 0.988 | 0.977 | 0.000 | | | | | | |
| Total hardness | -0.713 | -0.656 | -0.760 | 0.564 | 0.109 | 0.927 | 0.991 | 0.959 | 0.985 | 0.000 | | | | | |
| Chloride | -0.534 | -0.446 | -0.418 | 0.766 | 0.401 | 0.776 | 0.783 | 0.863 | 0.849 | 0.753 | 0.000 | | | | |
| TDS | 0.869 | 0.891 | 0.172 | 0.151 | 0.588 | -0.306 | -0.400 | -0.407 | -0.445 | -0.435 | -0.449 | 0.000 | | | |
| Total phy | 0.278 | 0.399 | -0.143 | 0.673 | 0.739 | 0.341 | 0.233 | 0.245 | 0.247 | 0.156 | 0.343 | 0.582 | 0.000 | | |
| Total zoo | 0.899 | 0.762 | 0.741 | -0.436 | 0.119 | -0.884 | -0.877 | -0.849 | -0.867 | -0.846 | -0.715 | 0.628 | -0.111 | 0.000 | |
| GPP | 0.907 | 0.769 | 0.749 | -0.389 | 0.168 | -0.866 | -0.857 | -0.819 | -0.840 | -0.826 | -0.663 | 0.625 | -0.087 | 0.997 | 0.000 |

*Value above 0.51 showing significant at 0.01 level. *Value between 0.51 and 0.4 showing significant at 0.05 level

Biochemical oxygen demand is defined as the amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic condition. The range of BOD was found to be from 12.52 to 17.50 $mgL^{-1}$ in monsoon and winter season, respectively. The comparison of BOD and DO in the present study indicated that there was an inverse relationship between both parameters (Figure 12). BOD was negatively correlated with DO (r = - 0.708, r = - 0.516) in winter and summer season, respectively. It showed positive correlation with temperature at 0.01 significance level.

COD determines the oxygen required for chemical oxidation of most organic matter and oxidisable inorganic substances with the help of strong chemical oxidant. In conjunction with the BOD, the COD test is helpful in indicating the presence of biologically resistant organic substances. The range of COD was found to be from 34.30 to 36.50 $mgL^{-1}$ in winter and monsoon season, respectively. (Figure 13). COD was positively correlated with BOD (r = + 0.968). It showed positive correlation with temperature (r = + 0.804) at significance level of 0.01.

Net primary productivity is the best criterion for assessing the trophic structure of a water reservoir. It is equal to organic matter synthesized by photosynthesis minus the rate of respiration. It depends upon light, temperature, water, nutrients and photosynthetic efficiency of producers. In Omkareshwar reservoir, the seasonal values of diel variations in net primary productivity were estimated to be 0.600 gC $/m^3$/ 3 h in summer which is the highest value. This clearly proved the role of light in net primary productivity. The increase in trophic production is highly significant and

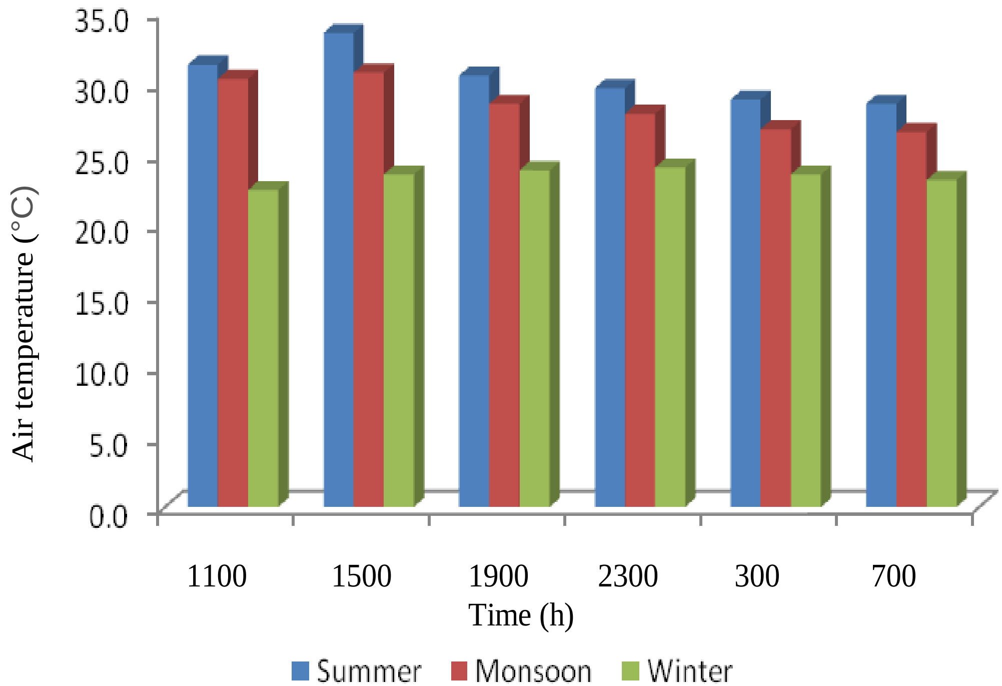


**Figure 3.** Diel variations in air temperature of different seasons.

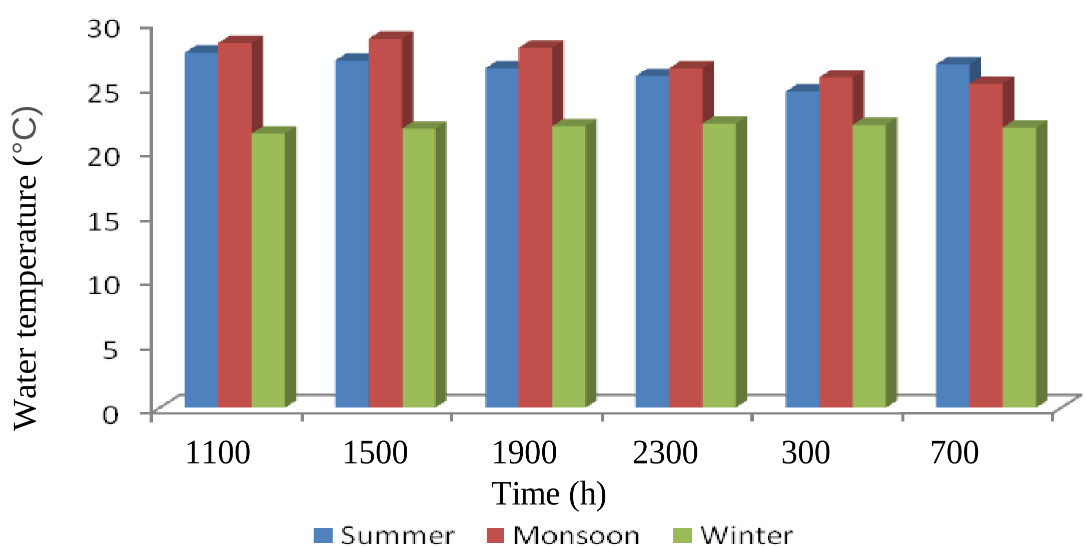


**Figure 4.** Diel variations in water temperature of different seasons.

showed rapid rate of eutrophication process in the reservoir. On the basis of primary productivity, the reservoir was found to be oligotrophic (Figures 14, 15 and 16). NPP showed negative correlation (r = -0.309) with total zooplanktonic productivity, while it was positively correlated with total phytoplanktonic productivity (r = + 0.185) at the significance level of 0.05.

The present investigations revealed that by and large the phytoplankton did not show any clear diurnal movement and remain concentrated at the surface or near surface zone. The zooplanktons are well known for their diurnal seasonal migration as they can actively swim towards most suitable environmental niche in the river (Pant et al., 1983; Dutta and Malhotra, 1987). The maxi-mum diel variation in total zooplankton population at surface was found during winter and summer whereas the minimal fluctuation occurred during the monsoon season. It is interesting to note that their number was found to be minimum on the surface around 1100 to 1500 h. It seems that the low oxygen conditions at the subsurface levels

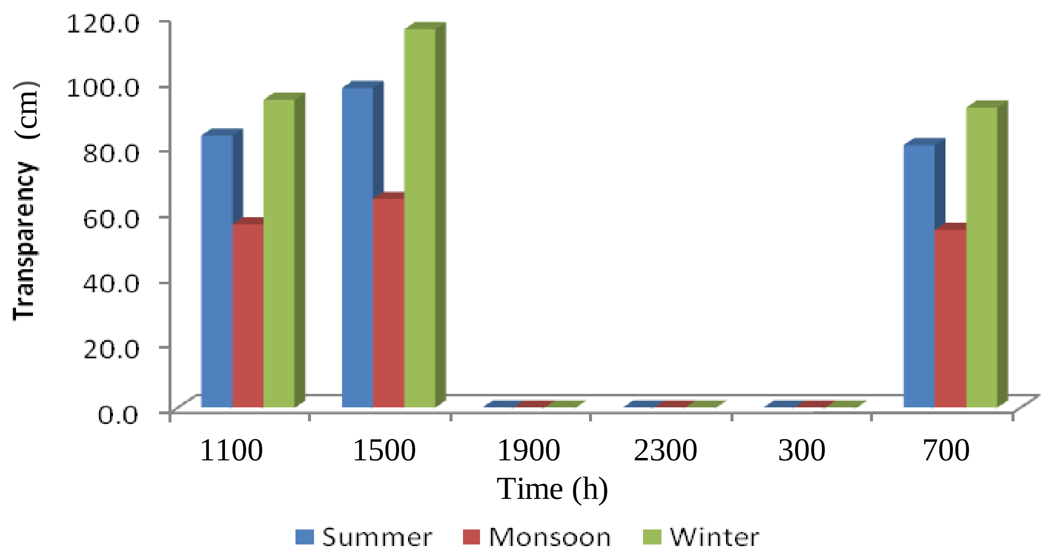


**Figure 5.** Diel variations in transparency of different seasons.

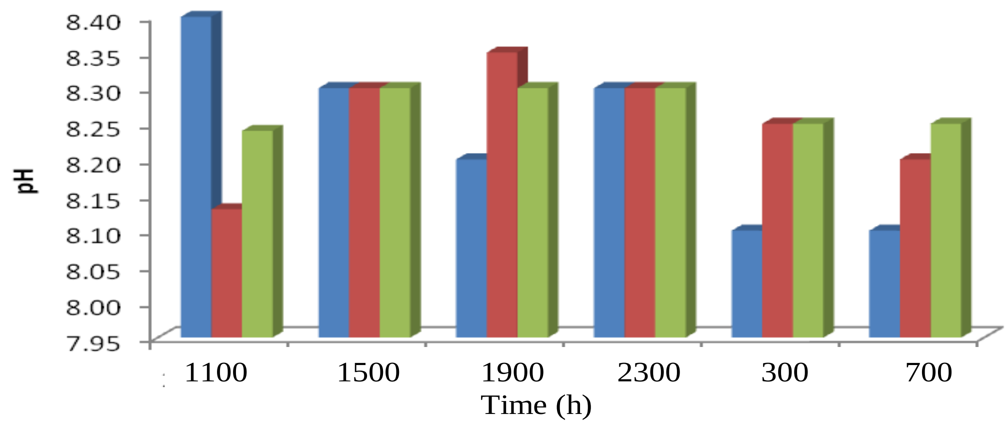


**Figure 6.** Diel variations in pH of different seasons.

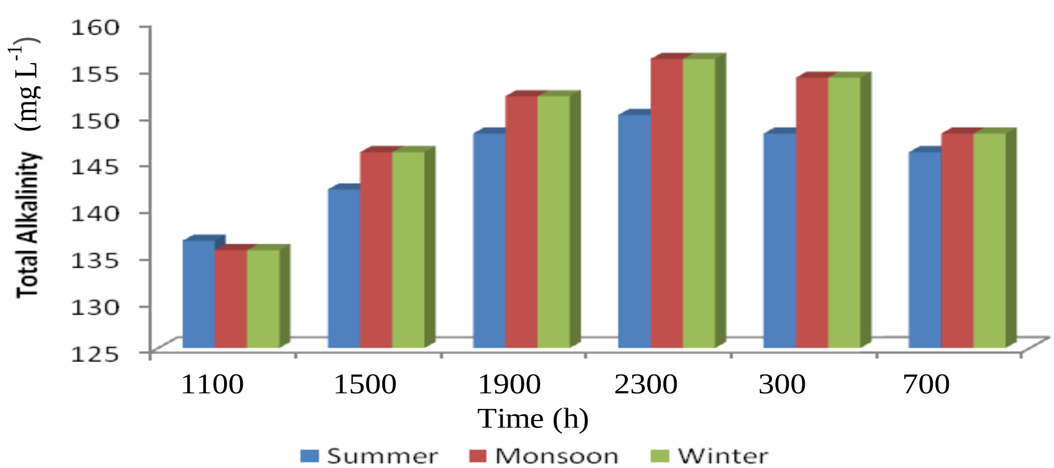


**Figure 7.** Diel variations in total alkalinity of different seasons.

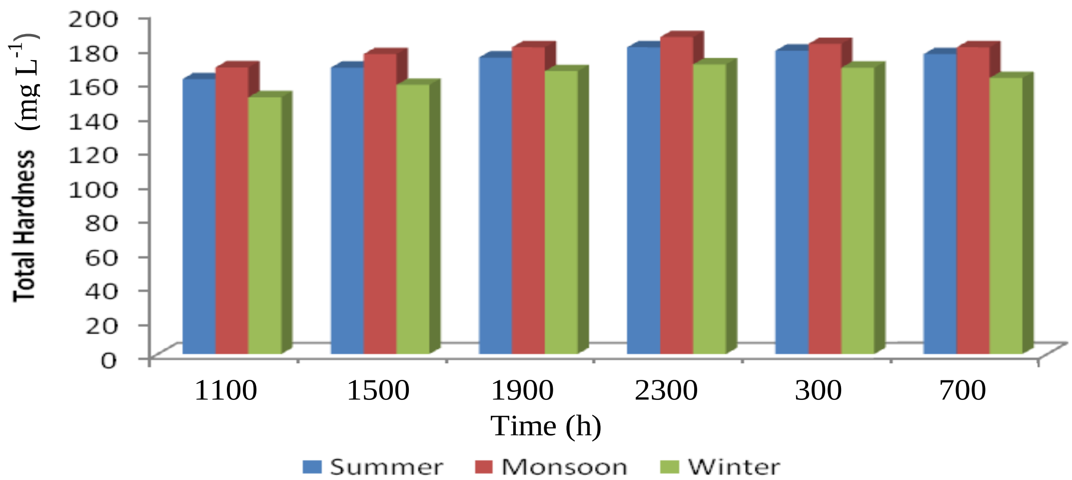


**Figure 8.** Diel variations in total hardness of different seasons.

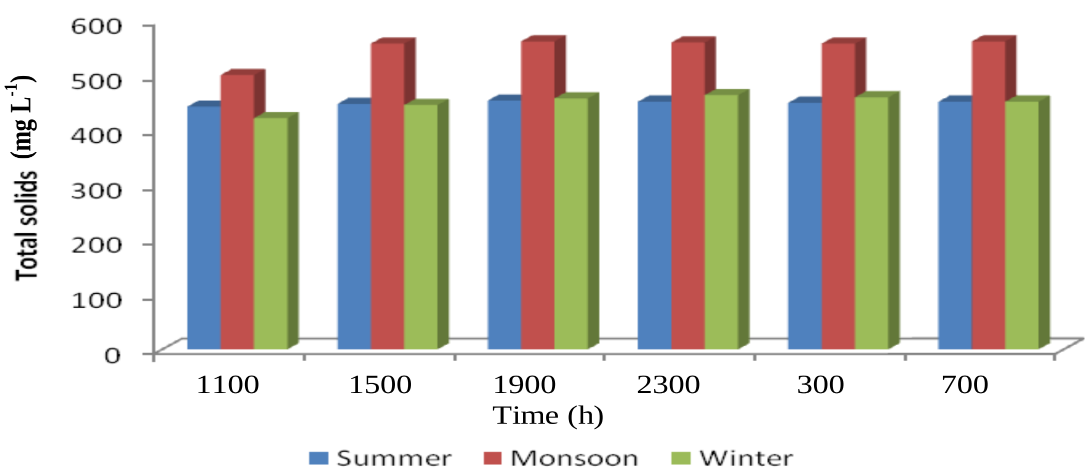


**Figure 9.** Diel variations in TDS of different seasons.

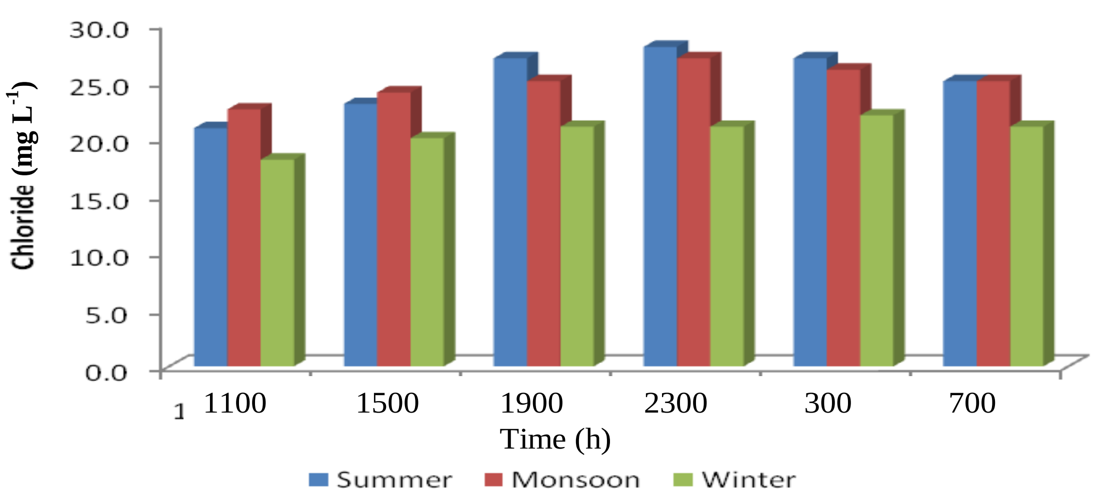


**Figure 10.** Diel variations in chloride content of different seasons.

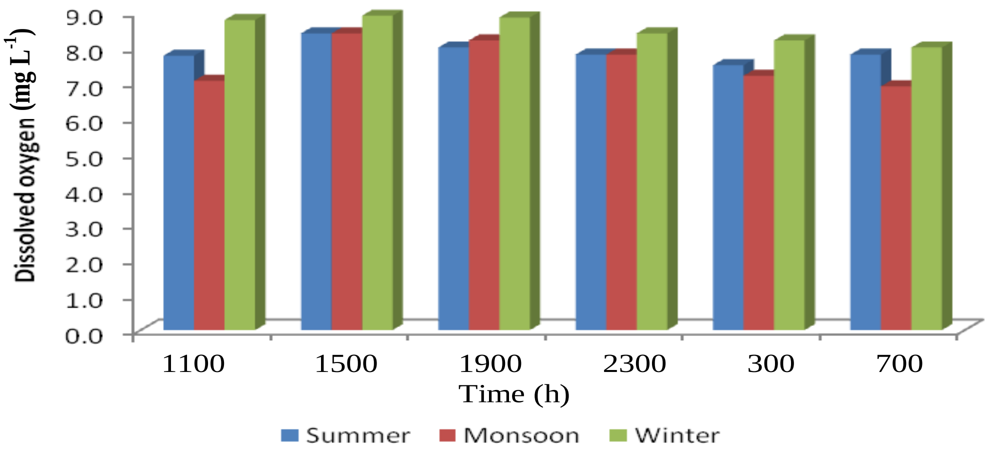


**Figure 11.** Diel variations in Dissolved Oxygen of different seasons.

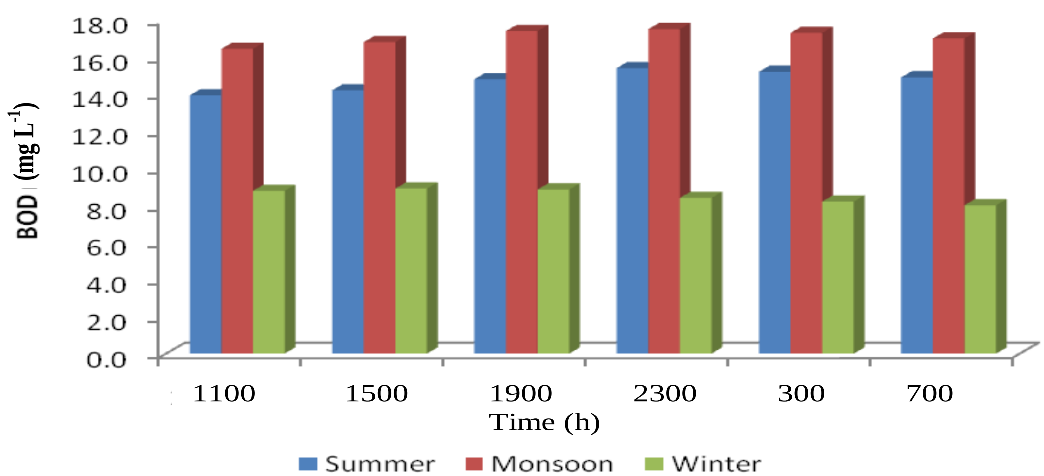


**Figure 12.** Diel variations in BOD of different seasons.

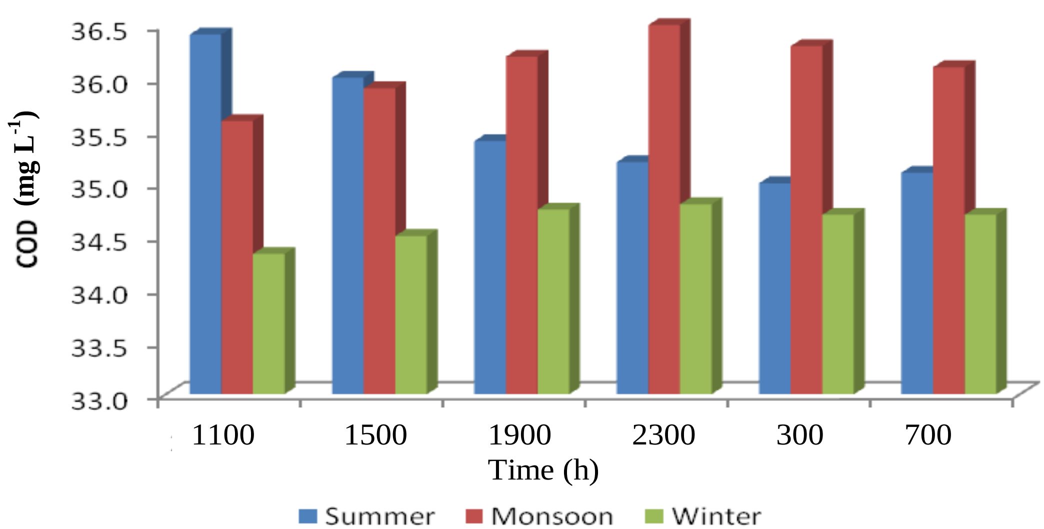


**Figure 13.** Diel variations in COD of different seasons.

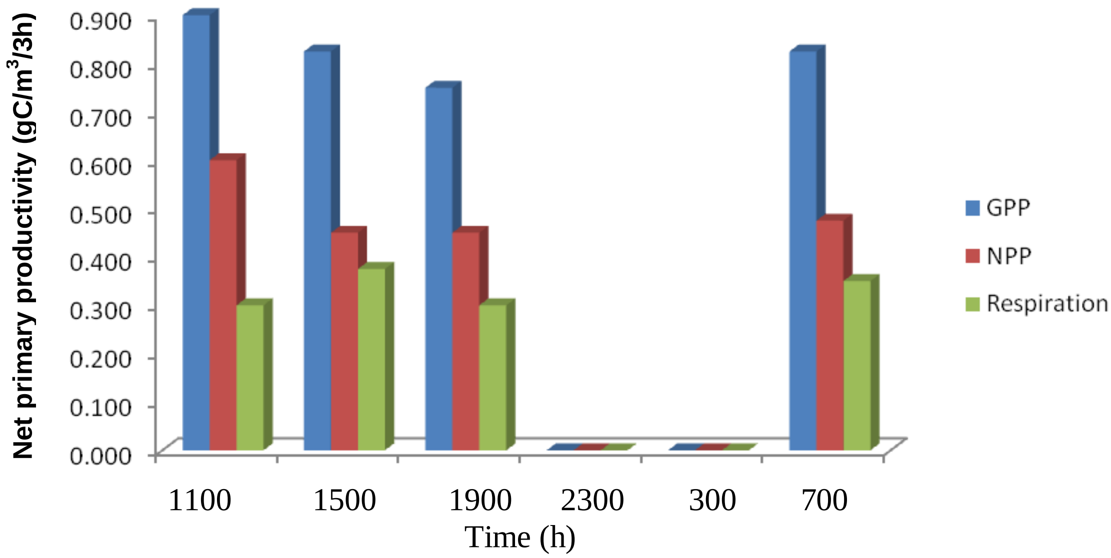


**Figure14.** Diel variations in primary productivity (gC/m$^3$/3h) during summer season.

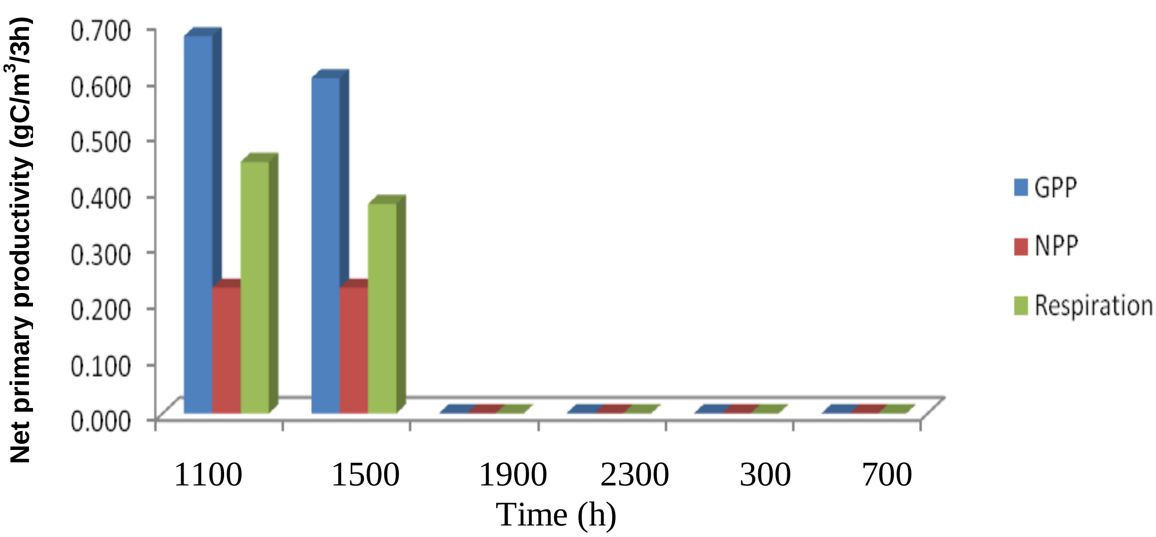


**Figure 15.** Diel variations in primary productivity (gC/m$^3$/3h) during monsoon season.

forced them to come out at the surface as is evident from almost even distribution of phytoplankton at all the depths (Bhattacharya et al., 1988). During monsoon, the maximum number of total zooplanktons on surface was encountered around 2300 h.

In the present study, the maximum diel variations in total zooplankton population were found at surface during winter and summer season whereas the minimal fluctuation occurred during the monsoon season. The changes in the physicochemical quality of the medium, space and time have a vital influence on the diel, seasonal migration of the planktonic organisms. The diel seasonal migration of zooplanktonic communities is known since long. The interaction of organisms to any one environmental factor is modified by the variations in another making it useless to seek any one factor being most important. Various factors are known to influence the diel seasonal movement in zooplanktons such as light, food, water current, dissolved oxygen (Jakhar et al., 1981). The maxima of total zooplanktonic population were observed at surface during night time. The present investigations revealed that phytoplankton did not show any clear diurnal movement when compared with the zooplankton population at Omkareshwar reservoir of Narmada River (Figures 17 and 18).

Now it was concluded that a striking diel variations

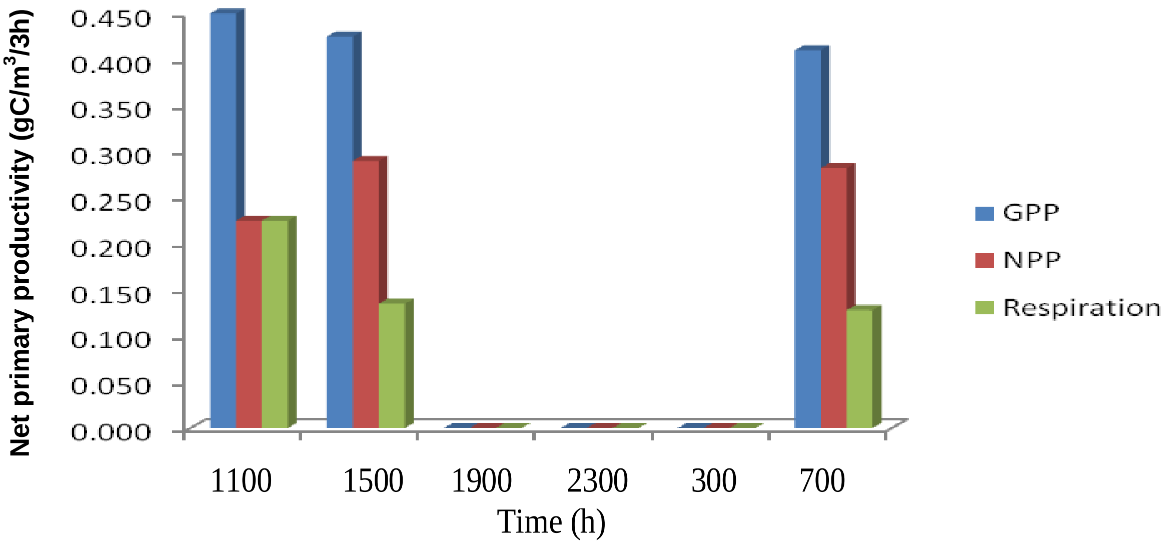


**Figure 16.** Diel variations in primary productivity (gC/m3/3hrs.) during winter season.

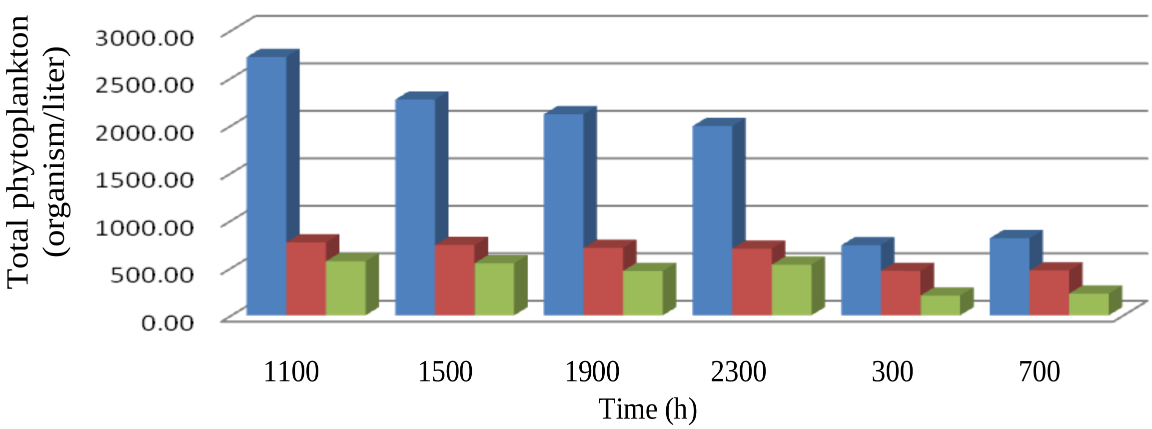


**Figure 17.** Diel variations in total phytoplankton during different seasons.

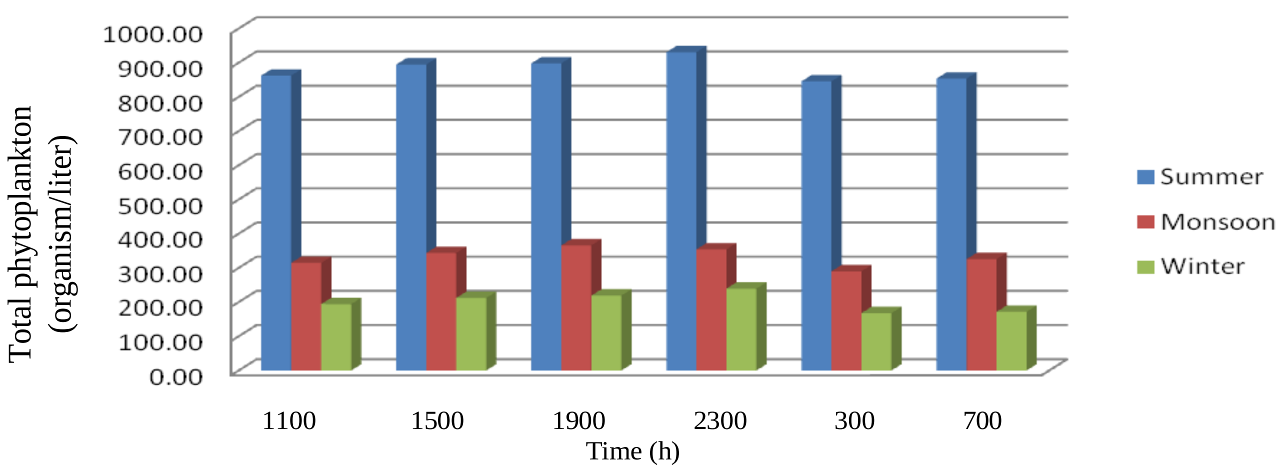


**Figure 18.** Diel variations in total zooplankton during different seasons.

were observed in selected physicochemical characteristics during 24 h. The physicochemical and biological characteristics have been variously employed in the classification of water bodies and the level of their eutrophication. (Sindhu and Sharma, 2008). The present study will be immensely helpful for further ecological assessment and monitoring of water quality, productivity, fisheries development and reservoir management policy in future.

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