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Full Length Research Paper

Determination of the Quality of Water in the Gammams River, Windhoek

Nnenesi Kgabi* & Gabriel Joseph
Department of Environmental Health Sciences, Polytechnic of Namibia, Private Bag 13388, Windhoek, 9000

Corresponding Author: Nnenesi Kgabi

ABSTRACT
In this study chemical (COD, BOD, Copper & nitrate), biological (total coliforms, faecal coliforms and E-coli) and physical (turbidity, TDS, DO & pH) water quality parameters were analysed for three study sites within the Windhoek City; and households in the vicinity of the Gammams river were surveyed using a standardized questionnaire. The overall quality of the Gammams River can be represented per sampling point from poor to good as: Windhoek West, Khomasdal, and Dorado Park. The Windhoek West site contained the highest number of damaged manholes, signs of improper w aste disposal, high turbidity, BOD, COD, coliforms, high nitrates and copper; while Dorado Park had clear water, no manholes, no waste, and all the other characteristics of a healthy/good quality river. The quality of Gammams River differs from point to point within the same stream. This indicates the possible risk depending on the topography, run-off and meteorology of the area. All the parameters measured during this study exceeded the set standards and guidelines. The results indicated high turbidity (9.99 NTU) upstream; faecal coliforms between 10 and innumerable counts/100 ml, and total coliforms (170 to innumerable); nitrate concentrations (1.5 to 28 mg/l) and dissolved oxygen ranging between 0.44mg/l and 11.41mg/l. The high coliform counts and other water quality parameters values exceeding acceptable limits are indicative of pollution from domestic wastes, open defecating, as well as from municipal sewer systems.

Key words: Water quality, Gammams River, water quality parameters

INTRODUCTION
Eighty percent of the rivers in Sub-Saharan Africa are trans-boundary (Duda & El-Ashry, 2000). These rivers have a high resource potential for socio-economic development through fisheries, tourism and recreation, irrigation schemes and hydropower generation. They also facilitate inter-country cooperation, meeting the goals and objectives of the African Union (UNECA, 2000). As a continent, Africa's proportion of freshwater resource is comparable to its portion of the global population.

Quality of water in rivers is a combination of their ionic composition, mineralization, the dissolved organic matter content, and the total and permanent hardness. The composition and characteristics of water in streams and rivers is determinative to a certain degree for its utilisation as a resource for variable economic activities; it is also crucial for the structure and function condition of aquatic ecosystems and the hydro-ecological safety of the river basins. The quality of a river at any point reflects several major influences including atmospheric inputs, climatic conditions and anthropogenic inputs (Bricker & Jones, 1995).

The Gammams River is a non-perennial river that starts in the undeveloped parts of Olympia near Auasblick. The river passes through some of the up-market residential areas of Windhoek and the stream is very polluted (Pedro, 2009). Windhoek, the capital city of Namibia, is located in the Central Highlands approximately 1,540m above mean sea level. The annual rainfall in Windhoek is approximately 370 mm, while the potential surface evaporation rate is in the range of 3,200–3,400 mm/annum (Department of Water Affairs, 1988). Windhoek obtains its water from the four main sources of water namely: Von Bach Dam, groundwater (50 municipal production boreholes), and reclaimed water from both the New Goreangab Water Reclamation Plant (NGWRP) and the Old Goreangab Water Reclamation Plant (OGWRP) (Lahnsteiner & Lempert, 2005). The water demand for the city is constantly increasing due to the rapid industrial developments and population growth. The pollution of surface water from urban streams may have the potential to pollute the underground water resources (Pedro, 2009).

Common water contaminants include suspended soil particles from erosion that cause turbidity and sediments in water bodies; inputs of nutrients that promote eutrophication, high primary productivity and depletion of dissolved oxygen; toxic substances such as heavy metals, pesticides and industrial chemicals and heated water from cooling of industrial processes. There are also additional possible effects on the water body which include; rise in organic load, metals and salt content, microbiological load, algal blooms, pharmaceutical products and endocrine disruptors (Iiputa et al., 2008). These may result in the following problems during treatment; taste and odour, filter clogging by algae, algae toxins, difficulties in treating the water, higher treatment cost, higher chlorine demand, bacterial and other growth in the pipes and distribution system, higher potential for pathogenic microbial pollution of the distribution system, metal deposits in reservoirs and distribution system, enhancement of corrosion, higher DOC and THM levels and micro-pollutants (Iiputa et. al., 2008)

Major factors affecting microbiological quality of surface waters are discharges from sewage works and runoff from informal settlements. Indicator organisms are commonly used to assess the microbiological quality of surface waters and faecal coliforms (FC) are the most commonly used bacterial indicator of faecal pollution (DWAF, 1998). These are normally found in water that is contaminated with faecal wastes of human and animal origin. Total coliforms (TC) comprise bacterial species of faecal origin as well as other bacterial groups (e.g. bacteria commonly occurring in soil). The coliforms are indicators of the general hygienic quality of the water and potential risk of infectious diseases from water (Fatoki et al., 2001).

The main physical/chemical parameters that are typically measured in water-quality studies are electrical conductivity, pH, temperature, suspended solids and nutrients (van Ree, 1999; Wang, 2001).

During the year 2010, the City of Windhoek, Health Services Department received several complaints of odour and mosquitoes from the residents living closer to the Gammams River (COW, 2010). There are no, known published documents on the quality of water in the Gammams River.
The aim of this study was to investigate the factors that affect water quality in Gammams River and quantify all appropriate parameters.

METHODS AND MATERIALS

The study population involved in this study was the residents living along the Gammams River in three suburbs namely; Windhoek West (S 22° 33` 35.0`` E 17° 03` 38.1``Elev: 1632m), Dorado Park (S 22° 34` 09.8`` E 17° 04` 23.7`` Elev: 1625m) and Khomasdal (S 22° 33` 18.5`` E 17° 03` 17.2`` Elev: 1643m) (inclusion criteria). Analysis of the biological, chemical and physical parameters of water from three (suburbs) different points within the Gammams River was performed. These three suburbs are residential areas with few markets and industries nearby, especially in Windhoek west. The majority of the residents using municipal portable water and all the sanitary services connected to the main municipal system belong to the middle income group especially in Windhoek west and Dorado Park, and only few in Khomasdal are of low income (COW, 2011). The municipal sewer systems pass along some sections of the river.

The qualitative variables were based on information from the survey or questionnaire and quantitative variables were obtained from analysis of different water quality parameters.
Water samples were collected three times on a daily basis from each sampling point for quality assurance purposes). Eleven (11) common water quality parameters namely physical (turbidity, TDS, DO & pH), biological (total coliforms, faecal coliforms and E-coli) and chemical (COD, BOD, Copper & nitrate) parameters were analyzed using different methods and compared with different standards as shown in Table 1 (Andrew et.al. (1998); Namibian water quality standards (2007); WHO (2011); Namibian Water Act 54 of 1956).

Table 1: Water quality parameters, units, analytical methods and standards used during the July - August 2011 for surface waters of the Gammams River

Determinants	Unit	Analytical Method	WHO standard	USEPA standard	Namibian water Standard (draft)	Water act (Guideline)
Turbidity	NTU	Turbidity meter		0.01-9.99 NTU	< 5	< 12
pH		HACH multi-parameter (pH electrode).			6,5-9,5	5,5% - 9,5%
Total dissolved solids (TDS)	Mg/l	HACH multi-parameter conductivity electrode.	No guideline		< 500 mg/litre above the intake potable water quality	Not more than 500 mg/l than
Biological Oxygen Demand (BOD)	Mg/l	WTW Manometric method		30mg/l	< 10	no value given
Chemical Oxygen Demand (COD)	Mg/l	AWWA 5220 D method (Merck Sq118: instrument)		3 - 150 Mg/l	< 45	75 mg/l
Dissolved Oxygen (DO)	Mg/l	AWWA 4500-O G method; WTW Electrode as an instrument	No guideline			A saturation of at least 75%

Copper (CU)	Mg/l&µg/l	Bicinchoninate method 8506		0.04-5.00Mg/l	< 500µg/l	1,0 mg/l
Nitrate (NO3)	Mg/l	Cadmium reduction method 8039, (Nitra Ver 5)	50 mg/l total nitrogen	0.30- 30.0 Mg/l	< 15	
Escherichia coli (E-coli)	EC/100ml				< 10	
Total coliforms (TC)	TC/100ml	AWWA9222D Membrane filtration			< 100	
Faecal coliforms (FC)	FC/100ml	AWWA9222B Membrane filtration			< 50	No coli should be counted/100ml

Purposive or judgmental and convenience sampling was used as sampling technique, based on specific parameters and residents along Gammams River. Sixty (60) households were selected, twenty (20) respondents from the community nearby each sampling point by selecting each third house since the total number of the houses nearby Gammams River was unknown.

RESULTS

Water quality parameters

A total of eighteen (18) water samples were analysed for eleven (11) water quality parameters; physical parameters (turbidity, TDS, DO & pH), biological (total coliforms, faecal coliforms and E-coli) and chemical parameters (COD, BOD, Copper & nitrate) using different analytical method.

Table 2 shows the laboratory results for the parameters measured during July and August 2011. The results show an overall deviation from the set standards on effluent water quality (see table 1).

Table 2: Laboratory average results on physical, chemical and microbiological parameters in water of the Gammams River during July and August 2011

Parameter	Windhoek West		Dorado Park		Khomasdal	
	July	August	July	August	July	August
Turbidity (NTU)	9.99	9.99	2.96	2.34	9.08	6.26
TDS (mg/l)	12.4	65	9.9	42	23.66	18.7
pH	7.9	7.8	7.3	7.6	7.4	7.3
Dissolved Oxygen (DO) (mg/l)	0.67	0.44	6.19	6.56	11.41	6.51
Biological Oxygen Demand (mg/l)	140	145	3	5	5	7
Chemical Oxygen Demand (mg/l)	198	294	20	103	33	163
Nitrate (mg/l)	6.5	28	2.68	1.5	-	2.1
Copper (mg/l)	-	1.25	-	0.25	-	0.88
E-Coli	Negative	Positive	Negative	Positive	Negative	Negative
Faecal Coliforms (FC/100ml)	Innumerable	Innumerable	10	24	220	3440
Total Coliforms (TC/100ml)	Innumerable	Innumerable	Innumerable	170	Innumerable	Innumerable

Table 3 Shows selected correlation coefficients for the parameters measured.

Parameters	Windhoek West	Dorado Park	Khomasdal
Cu and Turbidity	-0.564	0.265	-0.521
Cu and TDS	0.582	0.757	0.162
TDS and Turbidity	0.298	0.355	0.487
NO3 and Turbidity	0.472	0.529	0.348
NO3 and TDS	0.706	0.759	0.347
Cu and NO3	-0.360	0.938	-0.313
NO3 and pH	0.624	0.275	-0.836
TDS and pH	0.227	0.015	-0.313

High positive correlation ($r = 0.706$) between NO3 and TDS, followed by NO3 and pH, and NO3 and turbidity were observed at Windhoek West, suggesting that an increase in NO3 is linked to an increase in TDS, turbidity, and pH. A weak negative correlation between NO3 and Cu suggests that an increase in one parameter is linked with a decrease in another. This also may imply that the two do not necessarily have a common source.

On the contrary, the highest positive correlation was observed between NO3 and Cu at Dorado Park. This may suggest the same source or related source contribution mainly from some sewage piped system.

The highest negative correlation (-0.836) observed was between pH and NO3 at Khomasdal suggests. This suggests that low pH is associated with high NO3 at Khomasdal. The other two study sites however showed a positive correlation between the two parameters.

OBSERVATION RESULTS

An on-site evaluation of the area in the vicinity of the Gammams River was conducted using a checklist and the results obtained are summarized in Table 4.

Table 4: Observation/site inspection results obtained from the three sampling points in the Gammams River (July 2011)

Sampling Site	Presence of waste	Presence of manholes	Number of Manholes	Conditions of manholes	Any industries discharges	Presence of aquatic animals	Presence of odour	Presence of algae	Colour of water
Windhoek West	✓	✓	6	some are wet underneath and damaged	✓	×	✓	✓	Brownish
Dorado park	×	×	-	-	×	✓	x	✓	Clear
Khomasdal	✓	✓	3	Good condition well closed and no discharge	×	✓	✓	✓	Green

✓ = present x = absent - = Not applicable

Manholes were observed at Windhoek West (6) and Khomasdal (3) site. Signs of waste disposal into the river were also observed at the two sites. Some of the manholes observed at Windhoek West needed to be repaired. The Dorado Park site had no signs of waste and manholes, and the colour of the water was clear.

Residents Survey

A structured questionnaire specifically designed for conditions at the Gammams River, was administered successfully on 60 residents living nearby the River. The presence of odour was encountered more frequently in Windhoek west (100%), followed by Khomasdal (65%) Khomasdal (65%) and Dorado Park (55%). Most respondents (78.26%) described the smell as a mixture of "rotten eggs and urine", 15.22% "urine" and 6.52 % "rotten eggs".

The questionnaire responses reflected in Figure 1 also show that most of the respondents confirm that improper disposal of waste (38.6%) and open defecation (35.09%) into river is the main source of pollution.

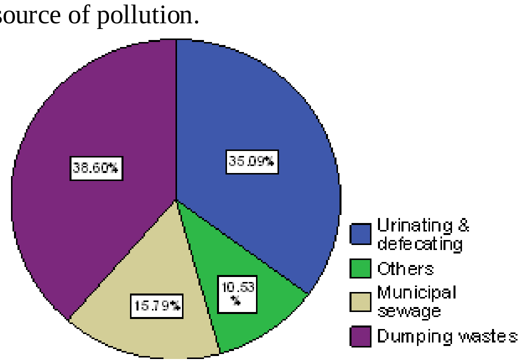

Figure 1: Activities contributing to pollution of Gammams River, July 2011

Most of respondents (55.93%) do not have gardens in their houses however 44.07% of the respondents reported that they have gardens and 68% admitted to using fertilizers.

The questionnaire responses also showed that children (55.9 %) whose homes are closest to the river visit the clinic on a monthly basis, 38.2% visit the clinic or hospital more than once a month. Only 5.9% of respondents indicated that, their children do not visit any clinic or hospitals. High fever was reported as one of the common health conditions (23.53%) experienced by the children, followed by running stomach (20.59%).

DISCUSSION OF RESULTS

Water quality parameters

Turbidity: Most of the Gammams River water quality parameters were found to be over the limit of set National and international standards and guidelines stipulated in Table 1. This shows that a lot of solids suspended in the river water are derived mainly from soil eroded by rain water and other activities surround the Gammams River (Denysschen, n.d). The presence of solid wastes (papers, plastics, old tins etc.) in the River can be also a factor contributing to the highest level of turbidity. It is evident from table 1 that most turbidity results from all sites do not met USEPA standards and National standards on effluent water.

Nitrate: The overall presence of nitrate in all sampling points ranged between 1.5 mg/l to 28 mg/l, this show that there is huge gap between the three sampling point as far as Nitrate concentration is concern. Windhoek West was recorded with the highest Nitrate concentration in August with average

28mg/l while Dorado Park was recorded with the lowest level of nitrate in the same month. Primary sources of organic nitrates at Windhoek West building constructors near the River and discharges from the municipal sewage systems. There is an increase in growth of green vegetation at Windhoek West mainly due to the high level of nitrate, since it does not evaporate and it is likely to remain in water until consumed by plants or other organisms.

Faecal coliforms: Faecal coliform bacteria are generally recognized as an indicator bacteria showing recent faecal pollution. Although fecal coliform bacteria are not necessarily dangerous to humans, their presence in streams indicates that the water is contaminated with fecal waste from warm-blooded animals (such as humans, domestic livestock, pets, and wildlife). For this reason, fecal coliform bacteria are known as "indicator organisms"; their presence in recreational waters indicates an increased risk to human health (Denysschen, .n.d). Table 2 indicates the level of FC in the range of 24-3440 FC/100ml. The highest level of FC apart from innumerable counts was recorded during August at Dorado Park, with 3440 FC/100ml. The faecal coliform levels also did not fall within the guideline value of 0 to 130 counts/100 ml set for full-contact recreation (DWAF, 1996). At this level there is a risk of contracting gastrointestinal illness as a result of full-contact recreation or direct consumption of untreated water (DWAF, 1996). The faecal coliform values in the river at most sites are also higher than the Namibian guideline of 100 counts/100 ml for water used for environment effluent water. The river is located near by the residential area, which could pose a significant health risk to human beings especially children.

Escherichia coliforms *(E.coli):* Escherichia cells are able to survive outside the body for a limited amount of time, which makes them ideal indicator organisms to test environmental samples for fecal contamination (Denysschen, n.d). There were no standards found on e.coli presence in effluent water apart from the proposed Namibian water quality standards.

Dissolved oxygen (DO): A good level of dissolved oxygen is essential for aquatic life (Tebbutt., 1998). Lowest level of DO was experienced during at Windhoek West and Khomasdal. The low level of DO in Windhoek West is justifiable since observation results showed no aquatic organisms at this point during observation/inspection. Temperature of stream water influences the amount of dissolved oxygen present; less oxygen dissolves in warm water than cold water, therefore the temperature differ in winter and spring. The low concentration in pH and moderate in dissolved oxygen is due to anaerobic conditions in the river from loading of high dissolved organic matter, which results in formation of ammonia and organic acids leading to a decrease in pH (Shrestha & Kazama., 2006).

Biochemical Oxygen demand (BOD): Biochemical oxygen demand is the oxygen required for the degradation of the organic matter biologically in water (Claude, 2000). It is evident from Table 2 & 3 the BOD concentration in all sampling points is ranged 3mg/l-145mg/. Windhoek West was recorded with highest BOD at all times (145 in August & 140 in July respectively) three times over the standards limit, while point B and C encountered BOD concentration <10mg/l. Based on the results there is a clear indication that point A is indeed polluted since is not a conducive environment for aquatic organisms. This may results from anthropogenic activities such as dumping of wastes (38.6%), urinating & defecating (35.09%) and industries discharges (15.79%) and others (10.53%) in the River as clearly shown in figure 1.

Chemical Oxygen Demand (COD): Table 2 & 3 shows the total quantity of oxygen required to oxidize all organic material into carbon dioxide and water (COD), with most of the results in all sampling points exceeding the two national standards limit average (Table 1) especially during spring season (August). Point A was recorded with the highest rate of COD in all seasons (294 mg/l in August & 189mg/l in July), and point A was identified with the lowest COD concentration (20mg/l). The results shows that there is a direct proportion between COD and spring time, since high rate were encountered during august (spring) compared to June, this may occur due to number of variables such as; temperature, pH, the presence of certain kinds of microorganisms, and the type of organic and inorganic material in the water (Fatoki et al., 2001)

Correlation of parameters

The strong positive correlation (r = 0.706) between NO3 and TDS observed in Windhoek West imply that the nitrate in water increases as TDS increases. This also suggests that potential sources of pollution in Windhoek West can be septic system or municipal sewers (James, 2009).

The strong positive correlation (0.938) between NO3 and Cu observed at Dorado Park can be attributed to the activities such as dumping of wastes and municipal discharge carried out nearby or in the River. A similar correlation was also reported by Shrestha, and Kazama (2006).

The positive correlation between Total dissolved solids and turbidity observed at all sites can be due to the presence other material that might reduce the clarity of water and the high TDS, may indicate the presence of other water quality problems (Denysschen.n.d).

OBSERVATIONS

The absence of aquatic animals in Windhoek West indicates the possible absence of dissolved oxygen (Fatoki et al., 2001). The bad smell, brownish water, and the presence of algae shows the presence of gross pollution in the Gammams River. The presence of industries near the Gammams River might have an impact on the quality of river water.

RESIDENTS SURVEY

The high level of odour encountered by the residents can be due to high levels of Total coliform bacteria in water which results in a reduction of oxygen demand or dissolved oxygen in the River. The experience of odour in stream water can be due to the presence of gases such hydrogen sulfide (rotten egg) and ammonia which caused by anaerobic conditions in the river from loading of high dissolved organic matter or TDS as shown in Table 2.

Municipal sewage system was also among the activities that were considered contributing to the pollution the Gammams River, this observation is similar to a study conducted by Fatoki et.al. (2001) in Umtata catchment were anthropogenic activities were confirmed as main contributors to the river water pollution. The fertilizer used in gardening may have an impact on water quality parameters especially inorganic fertilizers, due to the presence of super phosphate, ammonium sulphate, potassium sulphate and NPK (nitrogen, phosphorus & potassium) (Marvin & Susan., 2009).

According to DWAF (1998) most health conditions from water are transmitted through faecal waste. This study recorded health conditions experienced by resident along the Gammams river even though the majority of respondents (52, 94%) indicated that their children do not encounter any of the health conditions but high fever was recorded the as common health condition (23.53%) followed by running stomach and only one respondent (2.94%) stated that children experienced vomiting as well.

CONCLUSION

The overall quality of the Gammams River can be represented from poor to good as: Windhoek West, Khomasdal, and Dorado Park. The Windhoek West site contained the highest number of damaged manholes, signs of improper waste disposal, high turbidity, BOD, COD, coliforms, high nitrates and copper; while Dorado Park had no manholes, no waste, clear water, and all the other characteristics of a healthy/good quality river. The quality of Gammams River differs from point to point within the same stream. This indicates the possible risk depending on the topography, run-off and meteorology of the area. All the parameters measured during this study exceeded the set standards and guidelines.
The activities carried out by the residents as well as industries nearby the Gammams River play a crucial role on the quality of the river. A weak relationship between prevalence of children's diseases/health conditions was observed. Further studies are needed to ascertain the link between child health and water quality along the Gammams River.

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