Research Article
Open Access
CrossMark

Production boreholes water quality evaluation using GIS based geostatistical algorithms in Windhoek

Abstract

The acquaintance on the manifestation of production boreholes, its replenishment and chemical distinctive have distinct significance in semi-arid zone like Windhoek where production boreholes are partially source of water used for domestics. The goal of this research is to provide an overview for evaluation of production boreholes water quality in Windhoek by using GIS (Geographic Information System) and geostatistical algorithms. The production boreholes water quality parameters; pH, chloride, Iron, electrical conductivity and temperature were sampled and analyzed from production boreholes in Windhoek. Furthermore, maps of each parameter were produced by means of geostatistical (kriging) tactic. Moreover, semivariogram values were tested for different ordinary kriging models to ascertain the superlative fitted for the five water quality parameters and the superlative models were selected based on the average standard error, root mean square standardized error, root mean square error and mean square error. Five maps of the production boreholes water quality parameters were used to compute the production boreholes water quality map using the index technique. Therefore, pro-active measures must be taken into consideration to check the levels of pH, chloride, Iron and electrical conductivity and temperature to avert severe contamination and also to protect the production boreholes in Windhoek.

Keywords: production boreholes, water quality, geo-statistics, GIS

Volume 8 Issue 1 - 2024

Silas David

Environmental Engineering, Namibia University of Science and Technology, Namibia

Correspondence: Silas David, Environmental Engineering, Namibia University of Science and Technology, Namibia, Tel +264817180030, Email silasdavid71@gmail.com

Received: December 25, 2023 | **Published:** January 15, 2024

Introduction

Background

The quality of water in production boreholes is one of the vital concerns for human due to the fact that it is directly related with human welfare. The determination quality of public health depends to a greater extent quality of groundwater, particularly production boreholes. Moreover, during the construction procedure of the production boreholes; drilling fluids, chemical coverings and other material can find their way into the boreholes thereby contaminating the water. Furthermore, an open hole can be a direct way for contaminants from the surface to the aquifer thereby providing a perfect chance for chemical and bacteriological contamination to occur.[1] The measurement of pollutant concentration at all location is not always conceivable from time to cost perspectives in data collection. Consequently, prediction of values at other locations based upon selectively measured values represents a viable alternative. To envisage the concentration of pollutants at unmeasured locations, geostatistical technique is used. The main idea behind using Geostatistics is the characteristics of the earth that have some spatial continuity up to a certain lag distance. Kriging is a special case from inverse distance weighting (IDW) and other interpolation methods by taking into consideration the difference of estimated parameters. These methods (Geostatistics and Kriging) have several advantages, such as giving fair predictions with minimum variance and taking spatial correlation between the data listed at various places. Furthermore, kriging gives information on interpolation errors about the reliability of estimates. Geographic information system (GIS) is used to evaluate and map the spatial distribution of groundwater (production boreholes) quality.

Problem statement

About 10-15% of water in Windhoek are taken from production boreholes, with the high population rate growing rapidly in Windhoek. Reliance on production boreholes is increasing in Windhoek, creating challenges of provision of adequate quality and quantity of water. Furthermore, Windhoek is in crisis of water scarcity coupled with possible poor water quality. Water quality in production boreholes have to receive more attention to map the situation of water quality parameter in Windhoek.[2]

Objectives

Main objectives

This project aims at evaluating and analyzing production boreholes water quality in Windhoek, using a GIS based geostatistical algorithms.

Specific objectives

I. To check the pH, Iron, Chloride, electrical conductivity and temperature variation in production boreholes for water quality around Windhoek.

II. To use geostatistical analysis to analyze water quality in production boreholes around Windhoek.

Hypothesis

I. There is no major effect on the seasonal variation on the chemical parameters on the production boreholes water around Windhoek.

II. There is no major effect on the selected chemical parameters on the production boreholes water around Windhoek.

Justification

The population in Windhoek cannot be sustained without reliable access to save water and adequate quantity. Due to the population that is still growing this however leads to increased reliance on production boreholes water. Furthermore, this project will be an advantage as this will determine the water quality amongst production boreholes in Windhoek and recommending for suitable achievement or creating responsiveness about water quality. This project will be able to point out areas of poor and good quality of water availability amongst production boreholes in Windhoek. Moreover, information that this research will offer is, it will be used to conduct researchers, government organizations as well other developmental organizations such as non-government organizations to be able to develop strategic aspects, policies as well institutional infrastructures to be able to endow with quality and accessibility of water resources to the community of Windhoek at large (William, 2014).

Literature review

Global water quality

It is not only significant to have water accessibility but it is vital to have good quality water. Quality of water has however become a comprehensive concern of increasing significance, this directly have an impact on the social economic impacts. Therefore, this causes an increase towards the pressure from dissimilar developments that lead to deteriorating surface water and groundwater quality. Furthermore, water quality analysis in boreholes is an imperative action as this contributes directly and indirectly to reach the targets set out by Millennium Development Goals. However, the united nation environment program stressed that indicators on water quality can be used to demonstrate the progress towards the target to meet up the international agreements, by plotting the trends in water quality over time and space. This can be achieved only if there is continuous analysis of the boreholes water quality.[3]

Factors affecting water quality

The quality of water is affected by natural and human factors, individually or in cooperation. Therefore, the quantity of impact of these factors varies depending according to the type of sources that are involved. Furthermore, poor quality of water in boreholes causes economic cost such as health related costs and an increase in the cost of treatment of water.[3] Importantly, a wide range of natural influences are geological, hydrological and climatic, since these affect the quantity and the quality of water available. Their influence is generally greatest when available water quantities are low and maximum use must be made of the limited resource. Furthermore, although water may be available in adequate quantities, its unsuitable quality limits the uses that can be made of it M Meybecy.[4]

Water quality status in Windhoek

Management policies with regards to water quality are less advanced than some other aspect of water management in Windhoek. Deteriorating water quality is a serious issue in some areas. It is probably not a problem in much of the country as there are other issues, since the use of fertilizers and other agrochemicals are uncommon.[5] Furthermore, since 1990 water quality in boreholes has greatly improved. Water quality has improved from 70 percent in 1990 to 91 percent in 2015. Despite the improvement in the quality of water in Windhoek, this does not 0 that the water quality is virtuous. Due to environmental and geographic challenges, thus gives a greater chance for poor quality of water in the production boreholes in Windhoek.[6]

Study area

Windhoek is the largest capital city in Windhoek. Windhoek is located at the central part of Khomas highland plateau at the sea level of 1 700 meters, which is exactly at the country geographic center. The capital city of Namibia is seen as the social, economic and political cultural center of the country. Furthermore, Windhoek lies at $22^0$34’ 12”S and $17^0$5’1”E. The total area is 133km^2 with a current population of roughly 281 300 Figure 1.

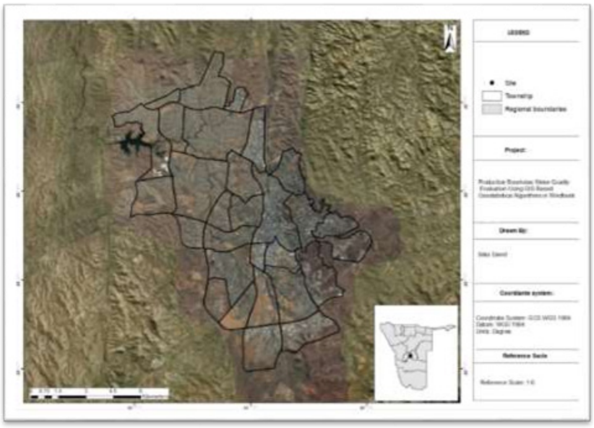

Figure 1 Study Area.

Materials and methods

Production boreholes were collected and analyzed by the department of infrastructure, water and waste management, City of Windhoek (COW). The samples were collected from the production boreholes. This project here used this data, which was provided by City of Windhoek from the department of infrastructure, water and waste management.

Geostatistical method

There are numerous tactics for interpolation, however kriging methods is the preeminent way for normal distribution data. Kriging was used in this project with its three steps.

Exploratory data analysis

To explore the data and confiscating outliers and to check data consistency, informality and identifying statistical distribution exploratory data analysis was used.

Structural analysis of data

Spatial correlation can be quantified with semivariogram. Kriging with semivariogram is associated to the anticipated square difference between paired data values and to the distance lag, by means of locations which are separated.

$$y\,h(\ ) = 1/2E\,z\,x\left[\left[(\ )\,z\,x\,h(\ -\ )\right]\right]^2$$

Discrete sampling function:

$$\gamma(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)} Z(x_i)-Z(x_i+h)$$

The function above clearly express the discrete sampling sites whereby *z(xi)* stands for the value of the mutable *z* for the location *xi*. *h* is the lag size and *N(h)* express the number of sets of sample point that is separated by *h*. In terms of asymmetrical sampling, it is infrequent for the lag (h) to be precisely equivalent. The semivariogram conspiracy is attained through calculating the values of the semivariogram at dissimilar lags. Furthermore, circular, spherical, exponential and Gaussian make available information about the spatial structure for kriging interpolation. Therefore ordinary kriging method is used in this research due to its uncomplicatedness and gives an accurate prediction in comparison to other kriging methods.

Citation: David S. Production boreholes water quality evaluation using GIS based geostatistical algorithms in Windhoek. *Int J Hydro.* 2024;8(1):1‒8.
DOI: 10.15406/ijh.2024.08.00366

Prediction

Circular, spherical, exponential and Gaussian were tested for the water quality parameter (Iron, pH, electrical conductivity, chloride and temperature) to select the superlative one. The values of mean square error, root mean error, average standard error, mean error and root means square standardized error were estimated to test the performance of the development models. However, if the forecasts are not prejudice, the mean error must near zero. The statistic associated with this have several hitches, as it depends on the scale of the data and how insensitive the data are to erroneousness in semivariogram. Moreover, an accurate model must have the mean standardize error to zero. Additionally, in order to make predictions, each kriging method gives the kriging variances estimation for the variability of the prediction from acknowledged values.

Groundwater quality

Groundwater quality is one of the most important sources of water that provide information on the quality of water to the concerned citizen of Windhoek at large.[7] The diagram below shows the quality of underground water in Windhoek, expressed as the concentration of total dissolved solids consisting of chemicals. Furthermore, this is based on the analysis of the groundwater database of Ministry of agriculture, water and rural development point data that were summarized to a 5×5 km grid.

The average TDS (total dissolved solids) equals the average TDS of all boreholes in each grid cell. This clearly shows that the quality of water in the production boreholes are so not virtuous, Windhoek is covered by boreholes in each grid that contains 0.12% of the maximum 0.85% of the total dissolved solids Figure 2.

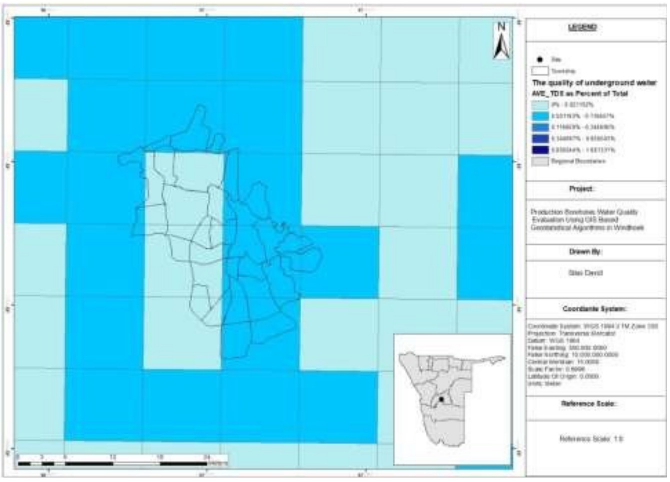

Figure 2 Groundwater quality in Windhoek.

Results and discussion

Analytical test results

The Table 1 below shows the analytical test report of the 26 production boreholes in Windhoek. The data was collected from 29 January to 2 February 2018.

Table 1 Production boreholes results

Boreholes	Result name	Units	Results
BH JJ 3A/5	Conductivity	mS/m 25°C	150
	pH	-	6.7
	Chloride (Cl)	mg/l	70
	Iron (Fe)	mg/l	0.1
	Temp	°C	35.7
BH JJ 3B/1	Conductivity	mS/m 25°C	135
	pH		6.82
	Chloride (Cl)	mg/l	57
	Iron (Fe)	mg/l	0.29
	Temp	°C	30.9
BH BL 5/4	Conductivity	mS/m 25°C	72
	pH		7.12
	Chloride (Cl)	mg/l	12
	Iron (Fe)	mg/l	0.41
	Temp	°C	38.6
BH BL 5/6 w586	Conductivity	mS/m 25°C	70
	pH		7.15
	Chloride (Cl)	mg/l	11
	Iron (Fe)	mg/l	0.35
	Temp	°C	38.1
BH AV 6/5	Conductivity	mS/m 25°C	69
	pH		7.25
	Chloride (Cl)	mg/l	10
	Iron (Fe)	mg/l	0.39
	Temp	°C	31.9
BH AV 6/7	Conductivity	mS/m 25°C	90
	pH		7.08
	Chloride (Cl)	mg/l	27
	Iron (Fe)	mg/l	0.76
	Temp	°C	30.8

Table 1 Continued...

Boreholes	Result name	Units	Results
BH AV 6/9	Conductivity	mS/m 25°C	66
	pH		7.07
	Chloride (Cl)	mg/l	7.9
	Iron (Fe)	mg/l	0.08
	Temp	°C	28.8
BH KES 7/1	Conductivity	mS/m 25°C	76
	pH		7.1
	Chloride (Cl)	mg/l	13
	Iron (Fe)	mg/l	0.69
	Temp	°C	31.2
BH KES 7/3	Conductivity	mS/m 25°C	68
	pH		7.38
	Chloride (Cl)	mg/l	13
	Iron (Fe)	mg/l	0.65
	Temp	°C	28.4
BH KES 7/6	Conductivity	mS/m 25°C	97
	pH		7.04
	Chloride (Cl)	mg/l	16
	Iron (Fe)	mg/l	0.11
	Temp	°C	29
BH KK 9/7	Conductivity	mS/m 25°C	410
	pH		6.89
	Chloride (Cl)	mg/l	220
	Iron (Fe)	mg/l	1.6
	Temp	°C	27.4
BH KA 10/7 w8427	Conductivity	mS/m 25°C	82
	pH		7.22
	Chloride (Cl)	mg/l	7
	Iron (Fe)	mg/l	0.62
	Temp	°C	29.4
BH GK 12/3 w26242	Conductivity	mS/m 25°C	54
	pH		7.07
	Chloride (Cl)	mg/l	14
	Iron (Fe)	mg/l	0.22
	Temp	°C	20
BH DI 13/1A w9679	Conductivity	mS/m 25°C	68
	pH		6.94
	Chloride (Cl)	mg/l	20
	Iron (Fe)	mg/l	<0.08
	Temp	°C	19.1
BH KK 9/18 w35612	Conductivity	mS/m 25°C	87
	pH		7.05
	Chloride (Cl)	mg/l	11
	Iron (Fe)	mg/l	0.81
	Temp	°C	28.6
BH GK 12/1B	Conductivity	mS/m 25°C	52
	pH		7
	Chloride (Cl)	mg/l	4
	Iron (Fe)	mg/l	0.55
	Temp	°C	18.9
BH DI 13/5	Conductivity	mS/m 25°C	61
	pH		7.07
	Chloride (Cl)	mg/l	14
	Iron (Fe)	mg/l	0.72
	Temp	°C	19
BH 9/17C	Conductivity	mS/m 25°C	58
	pH		7.22
	Chloride (Cl)	mg/l	5.9
	Iron (Fe)	mg/l	1.3
	Temp	°C	28.3

Citation: David S. Production boreholes water quality evaluation using GIS based geostatistical algorithms in Windhoek. *Int J Hydro.* 2024;8(1):1–8. DOI: 10.15406/ijh.2024.08.00366

Table 1 Continued...

Boreholes	Result name	Units	Results
BH _ 11/8B	Conductivity	mS/m 25°C	68
	pH		6.99
	Chloride (Cl)	mg/l	7.1
	Iron (Fe)	mg/l	2.5
	Temp	°C	26.8
BH _ 12/10A	Conductivity	mS/m 25°C	66
	pH		6.99
	Chloride (Cl)	mg/l	7.1
	Iron (Fe)	mg/l	2.5
	Temp	°C	26.8
BH _ 9/9A	Conductivity	mS/m 25°C	65
	pH		7.05
	Chloride (Cl)	mg/l	48
	Iron (Fe)	mg/l	1.8
	Temp	°C	27.1
BH _ 9/8C	Conductivity	mS/m 25°C	66
	pH		7.18
	Chloride (Cl)	mg/l	57
	Iron (Fe)	mg/l	0.16
	Temp	°C	27.7
BH _ 13/1E	Conductivity	mS/m 25°C	61
	pH		7.17
	Chloride (Cl)	mg/l	7.3
	Iron (Fe)	mg/l	0.41
	Temp	°C	18.5
BH _ 3A/6	Conductivity	mS/m 25°C	150
	pH		6.92
	Chloride (Cl)	mg/l	66
	Iron (Fe)	mg/l	1.3
	Temp	°C	37.1
BH _ 9/17E	Conductivity	mS/m 25°C	60
	pH		7.22
	Chloride (Cl)	mg/l	5.1
	Iron (Fe)	mg/l	1.9
	Temp	°C	28.3
BH _ 13/6	Conductivity	mS/m 25°C	61
	pH		7.16
	Chloride (Cl)	mg/l	8.3
	Iron (Fe)	mg/l	0.48
	Temp	°C	19.1

Water quality guidelines

The Namibian water quality guidelines specifically for production boreholes are essentially a user needs specification of the quality of water required for different domestic uses. The table below is intended to provide the information required to make judgment as to the fitness of water to be used for domestic's purposes, primarily for human consumption. Furthermore, the guidelines are applicable to any water that is used for production boreholes. The Namibian water quality guidelines are primarily source of information and decision-support to judge the fitness of water for use and for other quality management purpose. Water quality guidelines and standards for drinking water in Windhoek.

Parameter	Concern	Ideal guidelines	Acceptable standard	Unacceptable standards
Conductivity	H,I	<800 mS/m***	<300mS/m***	>800mS/m***
Iron	H,E	<200µg/litre	<300µg/litre	>300µg/litre
Chloride	H,I	<100 mg/litre	<600 mg/litre	>600 mg/litre
pH	I	6.0-8.5	9-Jun	>9
Temperature	E	Ambient temperature	Ambient temperature	Ambient temperature

Concern-refers to the impact if the limits is transgressed:

H= health concern; E= aesthetic effect; I= effect on infrastructure, structural

Table 2 Namibian Guideline: Guidelines for the evaluation of drinking-water for human consumption with regard to chemical, physical and bacteriological quality. Department of Water Affairs, South West Africa/Namibia, 20-10-1988.

Citation: David S. Production boreholes water quality evaluation using GIS based geostatistical algorithms in Windhoek. *Int J Hydro.* 2024;8(1):1–8. DOI: 10.15406/ijh.2024.08.00366

Table 2 Water quality guideline

Namibian guidelines for drinking water					
Parameter	**Unit**	**Group A**	**Group B**	**Group C**	**Group D**
pH	-	6.0-9.0	5.5-9.5	4.0-11.0	<4.0 >11.0
Conductivity	_mS/m	150	300	400	>400
Chloride	_mg/l	0.1-5.0	0.1-5.0	0.1-5.0	>5.0
Temperature	°C	NS	NS	NS	NS
Iron	µg/litre	<200	<230	299	>300

NS = Not specified

Comments:

There is no official guideline for free chloride. However with experience it was established for Windhoek that the water should have a free chloride residual of at least 0.5 to 1.0 mg/l in order to prevent microbiologically related problems in the distribution system.

Temperature gives an indication of the potential for bacterial growth and decline in free residual chlorine levels in the distribution system. Free residual chlorine concentrations are directly related to temperature.

Conductivity is a fingerprint of the water source and necessary to establish the source of the problem.

The disinfection efficiency of chlorine is directly related to the pH level of the water. Thus it is necessary to know what the pH is, in order to interpret chlorine levels and its effect on the reduction of bacterial counts.

General meaning of guidelines:

Group A: Water with an excellent quality – Water should ideally be of excellent quality or good quality.

Group B: Water with good quality.

Group C: Water with low health risk – If water is classified as having a low health risk, attention should be given to this problem, although the situation is not critical yet.

Group D: Water with higher health risk, or water unsuitable for human consumption – If water is classified as having a higher health risk, urgent and immediate attention should be given to this matter. Since the limits are defined on the basis of average lifelong consumption, short term exposure to determinants exceeding their limits is not necessarily critical, but in the case of extremely toxic substances such as cyanide, remedial procedures should be immediately taken.

Geostatistical modelling

Kriging variances must be precisely calculated due to the fact that they have a significant influence on some applications of kriging. If the root mean square error is close to the average square error, the predictions errors were correctly measured. However, if the root mean square standardized error is small than the average. The erraticism of the prediction is underestimated and this could as well be deducted from the root mean square standardized error statistic, this should be close to one. Furthermore, if the root mean square standardized error is greater than one. The erraticism of the predictions is underestimated, similarly if it is smaller than one the variability will be overestimated. A cross validation process was conducted and maps of kriging approximations were generated which provided a visual representation of the distribution of the production boreholes water quality parameters. Consequently, thematic maps for the production boreholes water quality parameters were created using ordinary kriging.

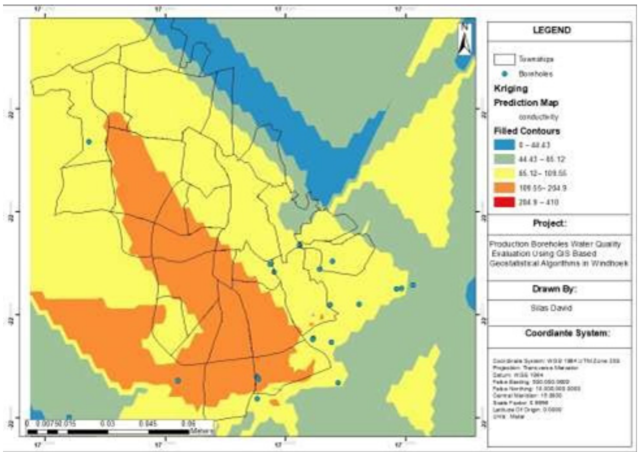

Figure 3 Electrical conductivity results concentration.

Electrical conductivity

In terms of electrical conductivity, the water tends to be of excellent quality. With thus it is clear that electrical conductivity in Windhoek is very low. No values exceeded in the production boreholes the values of unacceptable standards in connection with electrical conductivity which can cause health hazards in the production boreholes Figure 3.

Chloride

The ideal value to be considered is less 100 mg/litre. According to the prediction it clearly show that no values of that nature exceeds the ideal value as well the expectable value of any values less than 600 mg/litre. This results for the production boreholes to be in good quality in terms of chloride Figure 4.

Citation: David S. Production boreholes water quality evaluation using GIS based geostatistical algorithms in Windhoek. *Int J Hydro.* 2024;8(1):1–8. DOI: 10.15406/ijh.2024.08.00366

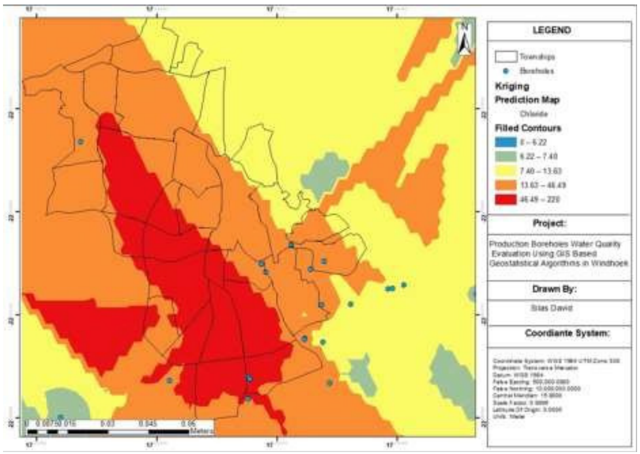

Figure 4 Chloride results concentration.

Iron

The Iron concentration is very low in the production boreholes. This results that the water quality is excellent in the production boreholes as all the values less than 200µg/litre which is the ideal guideline standard for water quality in Windhoek, Namibia Figure 5.

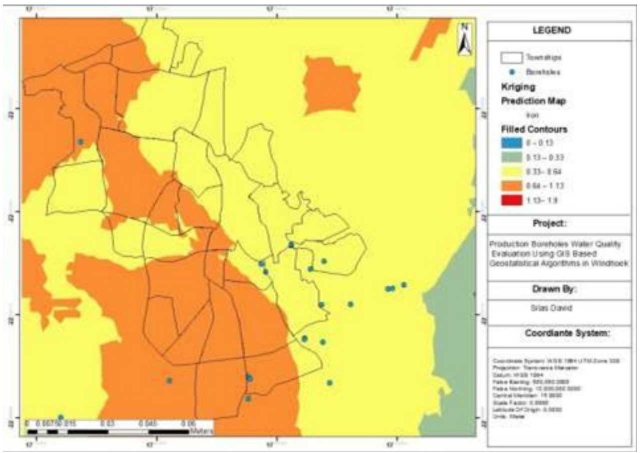

Figure 5 Iron results concentration.

pH

The hydrogen ion concentration tends to be less than the value 9. This results for the water in production boreholes to be of excellent quality Figure 6.

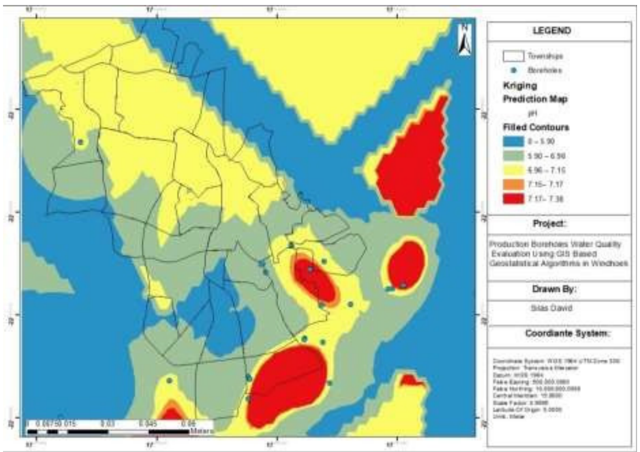

Figure 6 pH results concentration.

Temperature

The temperature has an effect on the production boreholes on south western part of Windhoek. The boreholes that are found at that location are affected by the temperature as the temperature is not Ambient (room temperature" or normal storage conditions, which means storage in a dry, clean, well- ventilated area at room temperatures between 15° to 25°C up to 30 °C). High temperature above the ambient range gives an indication of the potential for bacterial growth and decline in free residual chlorine levels Figure 7.[8,9]

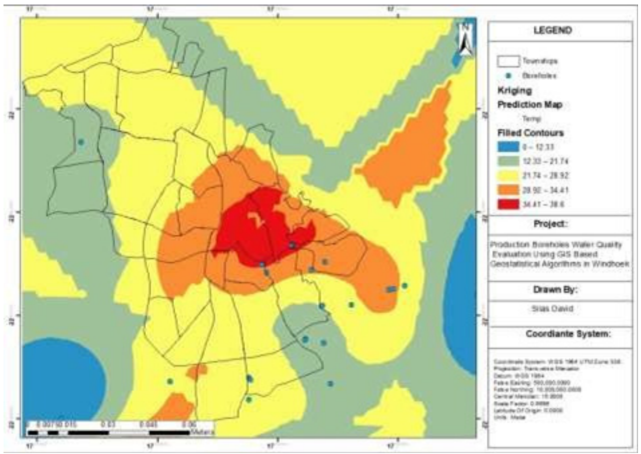

Figure 7 Temperature results concentration.

Conclusion

Geostatistical analysis methods, such as kriging are considered to be advantageous modus operandi for the evaluation and management of groundwater resources. This study uses kriging geostatistical technique and underground water quality to map the spatial variability of groundwater quality in the production boreholes. The production boreholes water quality analyses was done for Windhoek where all the production boreholes managed and owned by City of Windhoek were analyzed through using GIS based geostatistical algorithm. Furthermore, Ordinary kriging were carried out for distribution analysis of various water quality parameters. Results showed that all the parameter have good quality of water except for temperature which has an effect on the production boreholes. This can cause bacterial to build up in the production boreholes. Furthermore, Proactive measures needs to be taken into action to reduce this effect on the production boreholes. This study exemplifies geostatistical technique for water quality assessment and investigates spatial variations of water quality as a beneficial tool for the planners and decision makers to devise policy guidelines for efficient management.

Acknowledgments

First and foremost, I would like to thank the almighty for the strength and guidance. Many thanks to the City of Windhoek preferably, Mr. Ronny Tjitemisa (City of Windhoek GIS and CAD operator) at the bulk water and waste water division and Mrs. Ashipala (section scientist: process control and research) from the department of infrastructure water technical services for providing me with data, this project would not been a success without the data provided. Thanks to the City of Windhoek water testing lab at gammams for providing me with the water parameters results. Last but not least, I would like to thank my brothers Lysias and Benjamin Irua for the encouragement in this project.

Declaration

I Silas David declare that the contents in this report are of my own work (except where cited). This report has not been presented and it will however not be presented to other university for any award. I fully understand and acknowledge that my report can be made available to the public at large electronically.

References

1. Akpoveta O. *Assessment of Borehole Water used in the Vicinities of Benin, Edo State and Agbor, Delta State of Nigeria.* Nigeria: Current Research in Chemistry. 2011.
2. Bandela. *Study of water qaulity parameter assessement using GIS and Remote sensing.* India: University of India. 2016. p. 1–5.
3. Kapalanga TS. *Assessment and development of remote sensing based on algorithms for water quality monitoring in Northen Namibia.* Windhoek: Namwater. 2015.
4. M Meybecy E. *Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes.* United Nation: United Nations Environment Programme and the World Health Organization. 1996.
5. Day J. *The status of freshwater resources in Namibia.* Windhoek: Dictorate of Environment Affairs, Ministry of Environment and Tourism, namibia. 1997.
6. Worley A. *Five things you should know about the water quality in Namibia.* Namibia: The borgen project. 2017.
7. Jeihouni. *Groundwater quality assessment for drinking purpose using GIS modelling.* Tabriz: Department of Remote sensing and GIS, Faculty of Geography. 2014.
8. Gharbia AS. Groundwater quality evaluation using GIS based geostatistical algorithms. *Gaza: Scientific research publishing*. 2016;4(2).
9. William. *Assessment of borehole water quality and consumption.* Sudan: Institute of Environment Engineering. 2014.

Citation: David S. Production boreholes water quality evaluation using GIS based geostatistical algorithms in Windhoek. *Int J Hydro.* 2024;8(1):1–8.
DOI: 10.15406/ijh.2024.08.00366