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# Investigation of the Causes and Variations of Salinity in Drinking Water Wells in Pangani Town, Tanzania

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**Abstract** Fresh groundwater body constitutes an important resource for urban agricultural and industrial activities by which Tanzania dwellers depends daily on them. Its deterioration due to salinity especially in coastal aquifers emerges as a major challenge today in the country particularly in the coastal towns like Pangani in Tanga region. Pangani Town is characterized by slowly increasing population that depends largely on groundwater resource to suffice their day to day water demand. Water is abstracted from few boreholes and numerous shallow wells whereas bore holes serve only 48% of the population. Investigation of the causes and variation of the salinity levels in drinking water wells was achieved through physical observation, questionnaire, documents review and interview laboratory analysis and modeling of physiochemical data using AquaChem model for sourcing salinity. Questionnaire revealed low per capita water consumption such that 97.13% of respondent use less than 100litres per day which was subjective to unreliability and poor quality due to high salinity. The results portrayed by the Piper plot from the AquaChem model indicated that out of the 70% wells, 57% appeared to be highly intruded by seawater whereas 43% of the wells appeared to be slightly intruded. Overdependence of groundwater recourse causes over abstraction of the resource which may lead to the intrusion of seawater. Provision of embankment barriers will be the permanent solution to seawater intrusion.

**Keywords** Groundwater, Salinity, Seawater, Freshwater

**List of Abbreviations**

**EC**- Electrical Conductivity
**FAO**- Food and Agriculture Organization
**GIS**- Geographical Information System
**GPS**- Global Positioning System
**GW**- Groundwater
**NF**- Nano-filtration
**PAWASA**- Pangani Water Supply Authority
**PRBO**- Pangani River Basin Office
**SPSS**- Statistical Package for the Social Science
**TBS**- Tanzania Bureau of Standards
**TDS**- Total Dissolved Solids
**WHO**- World Health Organization

## 1. Introduction

Fresh groundwater body constitutes an important resource for urban, agricultural (irrigation) and industrial activities of which world dwellers depends daily for the mentioned activities and the freshwater hydrology should be in balanced form between rainfall and continual depletion by evapo-transpiration, extraction, discharge and mixing with seawater [1]. Water for human consumption should have appreciable characteristics in terms of quality depending on the anticipated use. Water salinity as one among the parameters in water quality is an induced phenomena in freshwater which are basically categorized into primary and secondary salinity. Primary salinity of water happens naturally as the result of precipitation interaction with the geological formation of the area that takes place in number of year whereas the secondary water salinity is one caused by anthropogenic activities that might result into more salts or enhance the rise of primary salinity into water [2], the two spectacles induce their effect in both ground and surface water.

Salinity in water may be due to the excessive presence of sodium (Na) and chlorine (Cl) elements mainly [3, 4, 5] but other elements contributing to salinity in water are magnesium (Mg), calcium (Ca), potassium (K) and sulfate ($SO_4$) and sometime may be remarked as Total Dissolved solids (TDS) and electric conductivity (EC). The increase of the mentioned parameters in water particularly drinking water well induces tensions to water supply authorities and water users that signify abundant pollution which may cause the closure of that potential well in use [6]. Thus salinization in groundwater has become a severe pollution torturing the world today due various environmental burdens such as rapid population growth, industrialization and rapid urbanization which results to increased water demand that threatens the groundwater resource. The potential factors leading to groundwater salinization especially in coastal zones are saltwater intrusion (inland flow of ocean), mineral dissolution due to rock weathering, population density [3, 4, 5] and anthropogenic activities revolution such as agriculture (especially irrigation scheme), industries and change of living standard.

Pangani Township is located in coastal area. It has pretty surface water source called Pangani River but due to poor resource utilization and financial challenges that exist among developing countries like Tanzania, the town is solely using groundwater in shallow wells as water supply where the dependable source is largely mentioned to be invaded by salinization and the case is further developing to cover the Pangani River too. The salinity problem had been observed on two boreholes that were operating and managed by Pangani water authority since 1962. These boreholes showed a continuous increase in salinity concentration that was measured in terms of electric conductivity (EC) up to year 2002 that demarked the collapse of the wells. The Pangani Township drilled another two wells that operates up-to-date. The problem seems to progress because there is severe corrosion and scale formation in pipes and its fitting.

The main objective was to investigate the causes and variations of salinity in drinking water wells at Pangani town in Tanga region. The specific objectives were: to identify freshwater sources available and their use in Pangani township, to determine the level of salinity of different sources of freshwater in study area, to identify the possible causes of salinity in Pangani township and to propose possible engineering solution for handling salinity situation.

## 2. Material and Methods

Investigation on the causes and variation of the salinity levels in drinking water was achieved through Physical observation, questionnaire, documents review, laboratory analysis and modeling of Physical-chemical results using AquaChem.

### 2.1. Physical Observation

The method involved acquisition of information from a primary source that was tangible and materially noticeable. The effects of salinity were possibly seen in pipes and storage facilities that appeared scaled and corroded respectively so with this method the implication was revealed, the process was associated with taking photo using digital camera.

### 2.2. Laboratory Analysis

The study involve analysis of various hydro-geochemical parameter of groundwater abstracted from the selected wells to show water quality status of the wells used for public water supply in Pangani Township involving both deep and shallow wells, these parameters are electrical conductivity (EC), salinity, pH, sodium, potassium, calcium, Bicarbonate, Chloride, Sulphate, Nitrate, Phosphate, Ammonia and hardness. Samples collected from eight easily accessible boreholes were analyzed for the mentioned parameters in Ardhi University laboratory.

#### 2.2.1. Water Sampling

Sampling of pumped water from the selected wells located with GPS was carried out four times at the interval of seven days. The samples were sampled after pumping the wells for 3 minutes and collected in labeled polyethylene bottle (1 litre) that was cleaned thoroughly with water to be sampled. The physical parameters (pH and Temperature) were recorded in situ. The samples were then conserved immediately in a portable cooler box and taken to Ardhi University laboratory.

#### 2.2.2. Laboratory Analysis

The analysis was done for the mentioned parameters in section 2.2 according to standard method for examination of water and wastewater [7]. The measurements that were done in the laboratory were checked for their correctness of result according to Hounslow, 2018 [8] that give limitation of ions exchange.

### 2.3. Documents Review and Interview

Materials regarding this study were obtained from various readings depending on availability and requirements for instance the study relied much on books, journals and articles of different authors that helped to have the corresponding overviews and basics on various aspects such as salinity, climatic conditions and its variability, geological formation and composition, topographical data of the study area.

However, Interview with responsible people from public and private entities helped to acquire geological and historical data of Pangani Township. Geological data to be used for simulation like lithology, Specific storage and Yield of the aquifer, constant head, as well as the pumping rate were obtained from the Pangani river Basin office (PRBO. Pangani water supply authority (PAWASA) and PRBO provided historical water quality data that were conducted in the year 2009, 2001 and 2013 by Ministry of Water, all this data are required to fulfill salinity simulation using AQUACHEM

### 2.4. Questionnaires

A set of questions were formulated for interviewing the community of Pangani Town. The questions aimed at identifying the available water sources, applicability and alternative sources of water at Pangani Town. 175 households were taken as sample size (about 10% of the Pangani population) from three wards in Pangani district in the way that at least 59 households were reached per every ward. The answered questionnaires were analyzed with the SPSS computer based software to obtain the statistical output of the interviewed respondents.

### 2.5. Modeling of Salinity

#### 2.5.1. Source of Salinity

Evaluation of source of salinity in the selected wells was done with the help of reactive test that basis on AQUACHEM model. In AQUACHEM interface development of the Piper Diagram (figure 2.1) was done regarding the chemical sample results in particular to the relative proportional of the major ions. For each of the water sample, a point was plotted in the lower left triangle based on the proportions of positively charged ions (cations) and the second point was plotted in the lower right triangle based on the proportions of the negatively charged ions (anions). These two points were extrapolated up into the upper diamond to place a third point [9].

In general, fresh groundwater samples will land near area labeled as ‘fresh’ in the upper diamond, while pure seawater will plot near the ‘sea’ label. Water that results from conservative mixing (mixing without ionic exchange reactions) between freshwater and seawater would plot along the line labeled ‘mixing’. When mixing occur in the presence of aquifer materials, ion exchange reactions often occur between the groundwater and the aquifer material, which alters the chemical composition of water. This change in chemical compositions results in a deviation from conservative mixing line on the piper diagram, moving the point upward into the upper portion of the diamond during intrusion and downward toward the lower portion of the diamond during freshening. Using this method, as generally shown in figure 2.2, it is possible to deduce not only if water sample is impacted by intrusion, but also if intrusion was getting worse (intrusion exchange) or better (freshening exchange) at the time sample was taken [9].

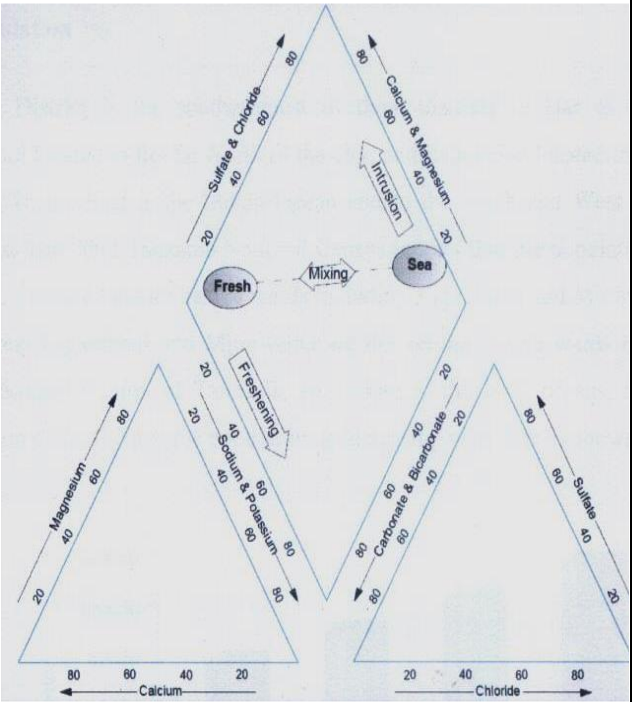


*Figure 2.1: Paper Diagram*

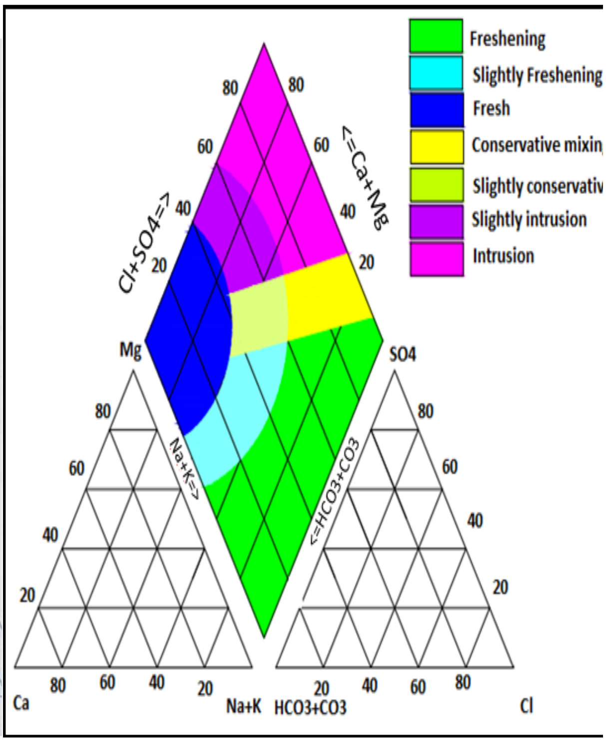


*Figure 2.2: Categorization of water*

**2.5.2. Salinity Variation**

Dynamicity of salinity in the study area was done with the help of SEAWAT- 2000 model which is a computer based program. SEAWAT is used to simulate variable-density, transient groundwater flow in three dimensions. Modeling using SEAWAT-2000 was done to give a complete understanding of cause of salinity in the study area. The program common input parameters are densities of both freshwater and seawater, hydraulic conductivity ($K_x$, $K_y$, And $K_z$), molecular diffusion, evapotranspiration, Total porosity, Specific storage and Yield of the aquifer, longitudinal, horizontal and vertical transpersivity, recharge rate, constant head, initial head and measure chloride concentration, as well as the pumping rate [10]. GPS device was used to collect coordinates of the sampled wells.

## 3. Existing Conditions

### 3.1. Geographical Location

Pangani is one among eight districts of Tanga Region in Tanzania found in between Longitude $5^{o}15.5'$S to $60^{o}$ S of the Equator and latitude $38^{o}35'$E to $39^{o}00'$ East of Greenwich Meridian (figure 3.1). The district comprises of thirteen wards (Pangani Mashariki, Pangani Magharibi, Bweni, Madanga, Kimang'a, Bushiri, Mwera, Tungamaa, Kipumbwi, Mikunguni, Ubangaa, Mkwaja, and Mkalamo) making up a total coverage area 1,830.8 km$^2$.

### 3.2. Topography and Climate

The climatic condition of district in terms of precipitations annually is divided into three seasons namely the long rain Season (occurs in the month of March to June), short Rains Seasons (occurs October to December) and The Occasional shower season (occurs June to September) resulting to the average rainfall per annum ranging from 800 – 1400 mm.

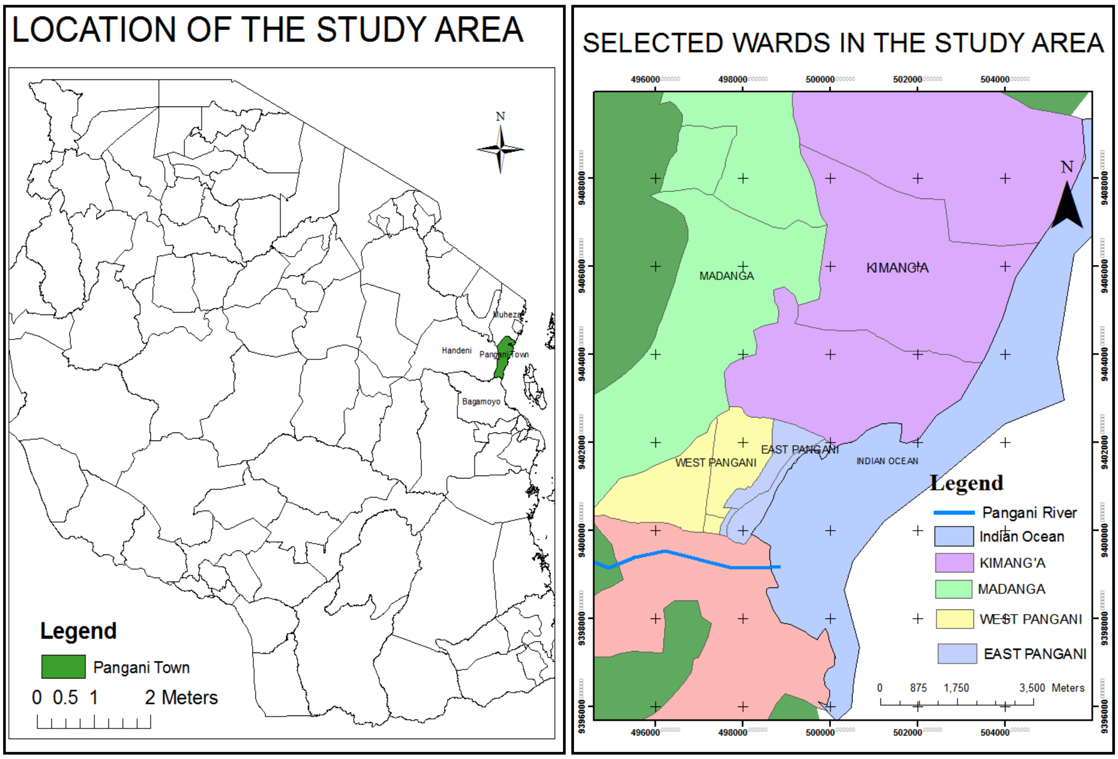


*Figure 3.1: Location of selected study area in Pangani district*

### 3.3. Population

Pangani district population shows a significant geometric increase in population with a rate of 1.1% as stipulated in population's census of year 2012 [11] (Figure 3.2).

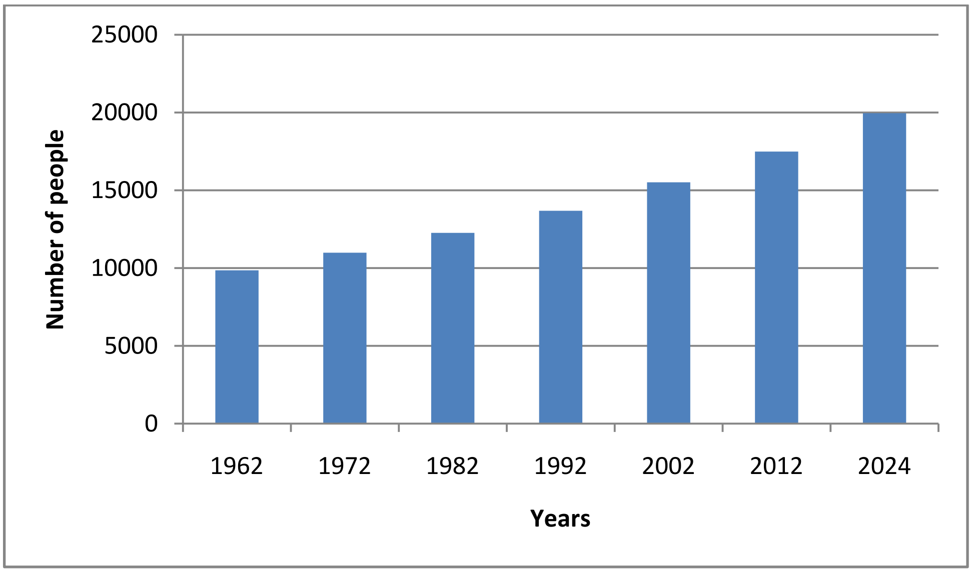


*Figure 3.2: Pangani population indicating increase trend*

### 3.4. Water Supply

According to Pangani Town Water Supply authority, the authority offers its service to only four wards (Kimang'a, Madanga, East Pangani and West Pangani wards) out of thirteen wards (figure 3.2) which in total make a population of 17,500. Since the water is inadequate, it is intermittently supplied to the community.

### 3.4.1. Water Sources

Pangani Town and its collaborating wards despite of being located along Pangani River Basin with Pangani River plentiful of water but it largely depend on groundwater source. Pangani water supply department started supplying water to the community using two boreholes (approximated 45m deep) (Plate 3.1) with yield of 31 $m^3$/hr and 32 $m^3$/hr, respectively. The water supply distribution system was upgraded to dead end pipe system with gravity scheme using the same boreholes. With years the well showed a significant decrease in the production capacity. This decreasing in production was caused by decreasing in the hydraulic head and increasing in salinity that caused failure in casing, still pipe deterioration. Due to those failures these wells were abandoned. In year 2002 the authority came into decision of drilling new two wells (Plate 3.2) situated at a separation distance of about 25m, the wells came into effective usage in the year 2003.

These new wells are currently supplying water in Pangani town to the same locality though these are electrically driven with submersed pumps (pump capacity is 675$m^3$) that pump water to the storage facility located about 0.8km from the wells. From storage tank, water flows by gravity to the distribution system. The average production rate of the two wells is 26,221 $m^3$/month equivalents to 36.42 $m^3$/hr in the interval of ten years.

*Plate 3.1: Abandoned boreholes due Increase in salinity level*

*Plate 3.2: Existing boreholes in operation*

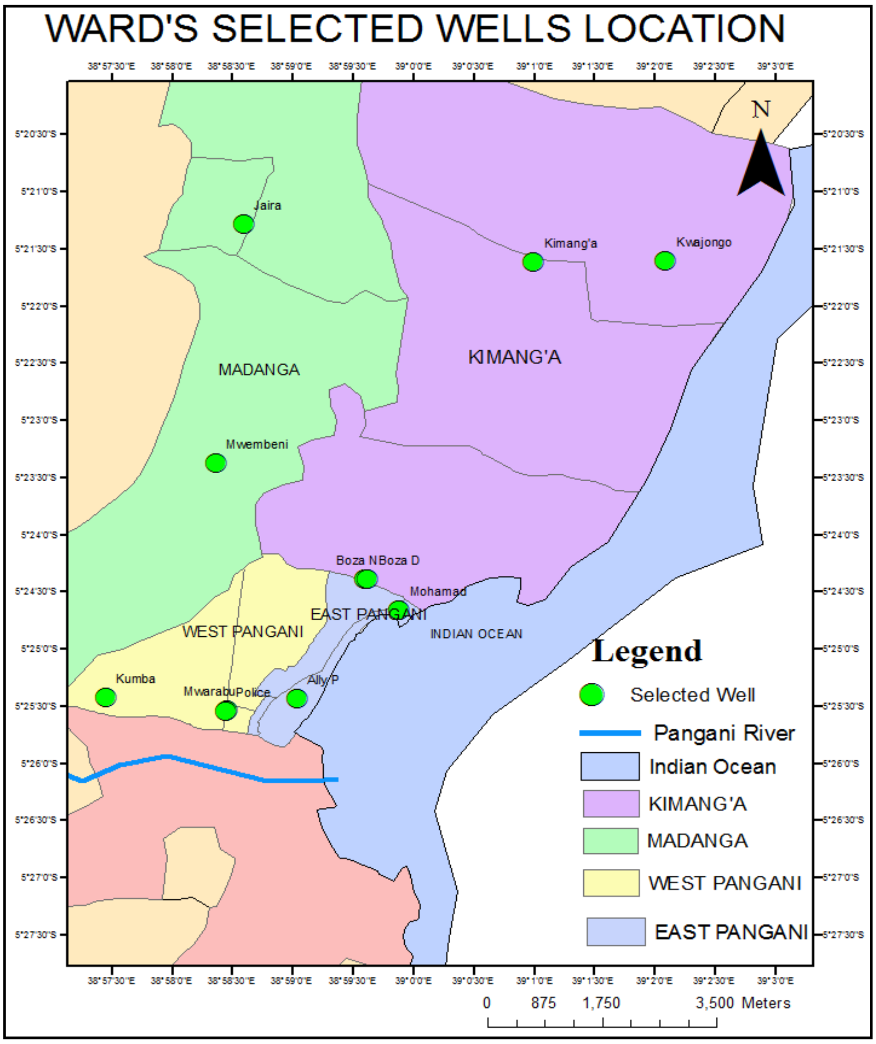


*Figure 3.2: Four wards served by Pangani Water Authority*

### 3.4.2 Water Demand

Population that is serviced by Pangani Town Water Supply authority varies yearly, this variation goes together with the increasing demand of water to the community. The per capita water consumption estimated to be 120 l/day. According to figure 3.3, Pangani Town Water supply Authority is capable of providing water for only 48% of the population demand.

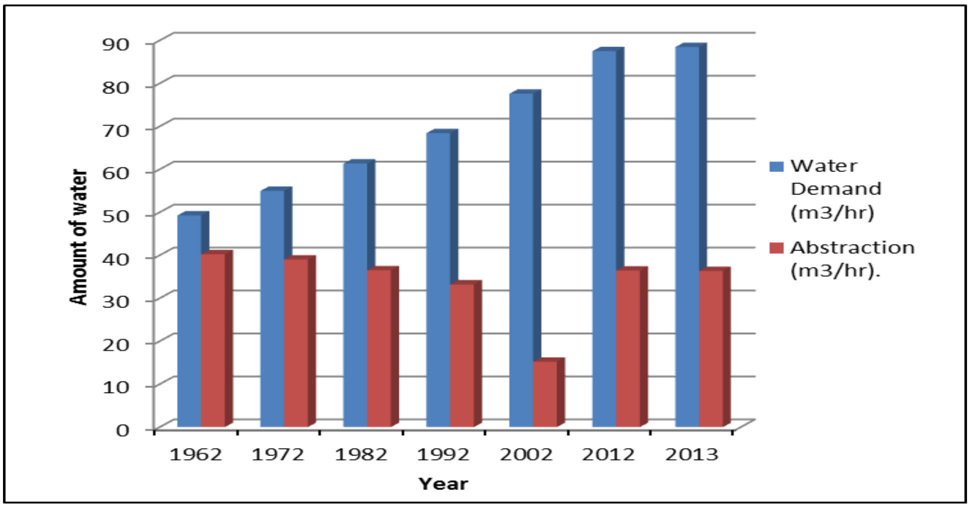


*Figure 3.3: Population water demand in relation to water produced in wells*

**3.4.3. Domestic Consumption of the Water**

As indicated in figure 3.4, the water consumption per household per day is 100-200, 200-300, 300-400, 400-500 and above 500 litres with corresponding rates of 1.71%, 60.57%, 21.14%, 13.71% and 3.86%, respectively. The results revealed that 97.13% of the population's water consumption was below 500 litres per day. According to household budget survey of 2012, one household has average of 5 people and therefore this means that 97.13% of the population has water consumption per person below 100 litres.

To cutter for water shortage, the community has alternatively indulged in digging shallow wells and this was mainly practiced in West and East Pangani where in every radial of 200m there one shallow wells (plate 3.3). These shallow wells due to high salinity are not use for drinking water instead they are used for other domestic activities like washing.

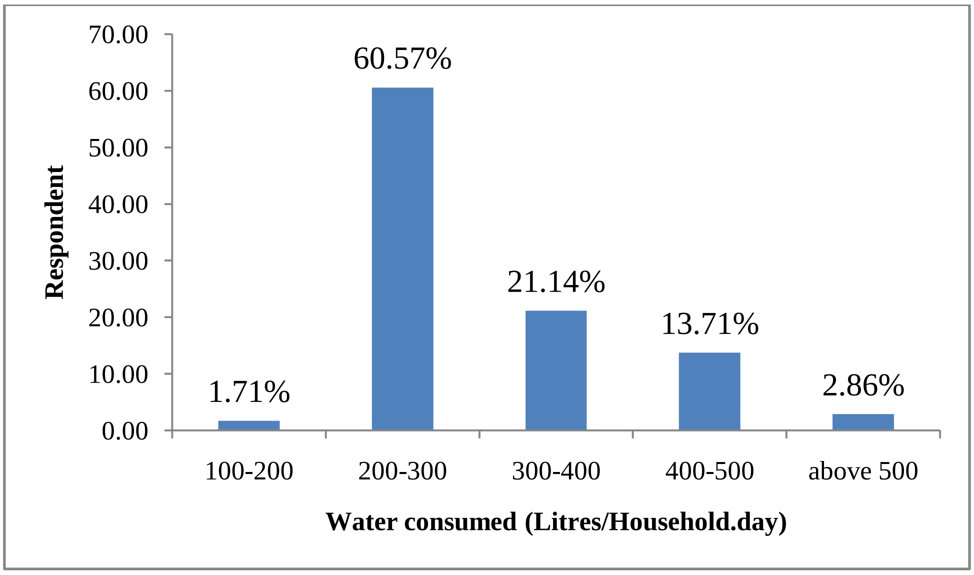


Figure 3.4: House hold water consumption per day

*Plate 3.3: Existing shallow wells in Pangani Town*

**3.4.4. Socio-Economic Activities**

Pangani community largely depends in agriculture that depends on precipitation occurrence. 73.71% of the population cultivate food crops and cash crops commonly sisal and coconuts. Those who practice agriculture and small scale livestock keeping (open grazing) were about 19.43% of the population. 6.86% of the population practice only livestock keeping (Figure 3.5).

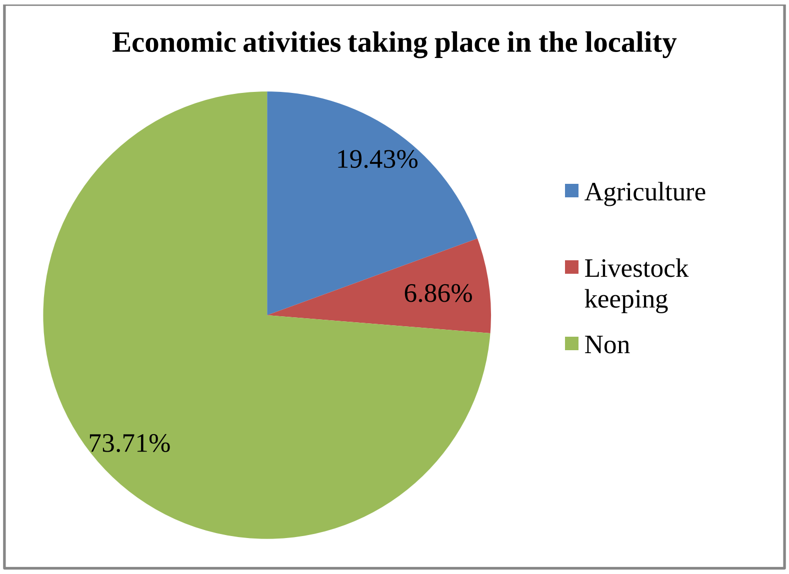


*Figure 3.5: Economic activities taking place in the locality*

### 3.4.5. Sanitation Situation

Pangani residents use traditional methods to dispose solid waste such as open burning, burying and haphazard throw along streets. In Pangani district, the type of sanitation opted is onsite as because there is no sewerage system as a result there might be a direct contamination of groundwater by pit latrine wastewater plate 3.4 indicate.

*Plate 3.4: Nature of sanitary facilities used*

## 4. Results and Discussions

### 4.1. Groundwater Quality Characteristics

Physical and chemical characteristics of groundwater were obtained through laboratory analysis. The discussions on characteristic linked the results obtained through interview, laboratory analysis and physical observations.

Physical characteristics of groundwater analyzed at Pangani were pH, Temperature, Salinity, EC and TDS while chemical parameters analyzed includes Calcium, Magnesium, Sodium, Potassium, Chloride, Sulphate, Nitrate-N, Phosphate, Ammonium-N, Bicarbonate and these were checked for their quality in measurement as in table 4.1.

**Table 4.1:** Reliability of Water Quality Data Analyzed (Hounslow, 1995)

| TEST | Limit Value | Number of samples | Comments | Results |
|---|---|---|---|---|
| Anion-Cation balance $\% differenc = 100 \times \frac{\sum cation - \sum anion}{\sum cation + \sum Anion}$ | $> 5\%$ | 8 | All samples are within >5% | Passed |
| Measure TDS-Measured EC $0.55 < \frac{TDS_{measured}}{EC_{measured}} < 0.7$ | $< 0.55\& > 0.75$ | 6 | Not within <0.55&>0.75 | Failed |
| $\frac{K^+}{Na^+ + K^+}$ | $> 20\%$ | 4 | Within >20% | Passed |
| $\frac{K^+}{Na^+ + Cl^-}$ | $< 50\%$ | 7 | Within <50% | Passed |
| $\frac{Ca^+}{Ca^+ + So_4^{2-}}$ | $< 50\%$ | 8 | Not within <50% | Failed |

### 4.2.1. Physical quality

In accordance to respondents at Pangani Township that were interviewed, water showed mainly two physical characteristics namely taste and hardness (figure 4.1a). 80% 0f the respondent found mentioning taste and hard to be the main problematic physical features in their water. 96% of the respondents said water taste is saline and they claimed to find settled white crystals (Plate 4.1) in their water after five to six hours of the storage containers. Furthermore, the salinity of the selected wells used by the community for various domestic activities revealed the high salinity (figure 4.1b).

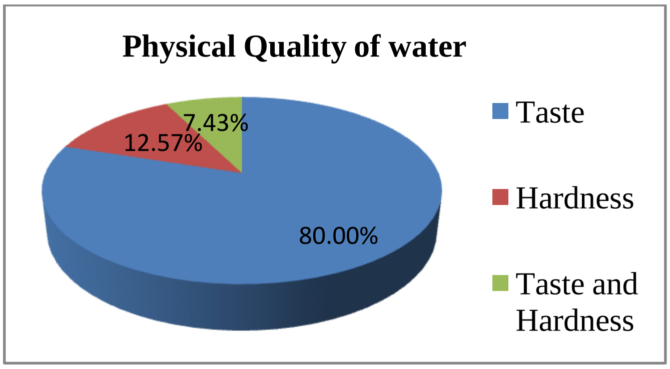


*Figure 4.1a: Physical water quality interview responses*

*Plate 4.1: Respondent showing crystal and white films formed in water*

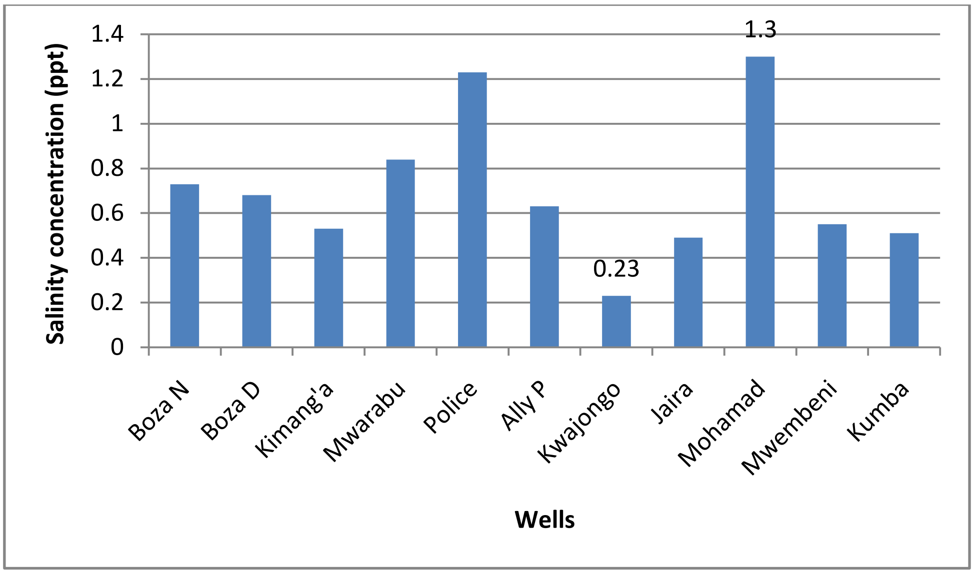


*Figure 4.1b: Comparison of salinity in Selected Wells in Pangani*

Variations of physical-chemical characteristic of groundwater in long trends were also assessed by examining historical data from year 2001 to 2013. Figure 4.2, 4.3, 4.4 and 4.5 describe the trending variation of Electrical conductivity, salinity, Total dissolved solids and Chloride, respectively in the year 2001, 2009, 2013, 2014 for Boza N and Boza D located in Kimang'a ward. The trend shows a decrease and increase in the variables for instance the increase in salinity is associated with high abstraction of groundwater which was likely to cause seawater intrusion as reported by the PAWASA manager.

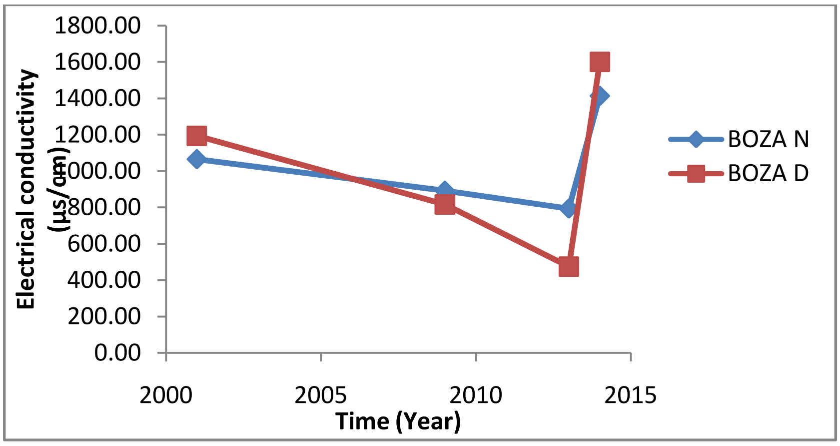


*Figure 4.2: Electrical conductivity variations*

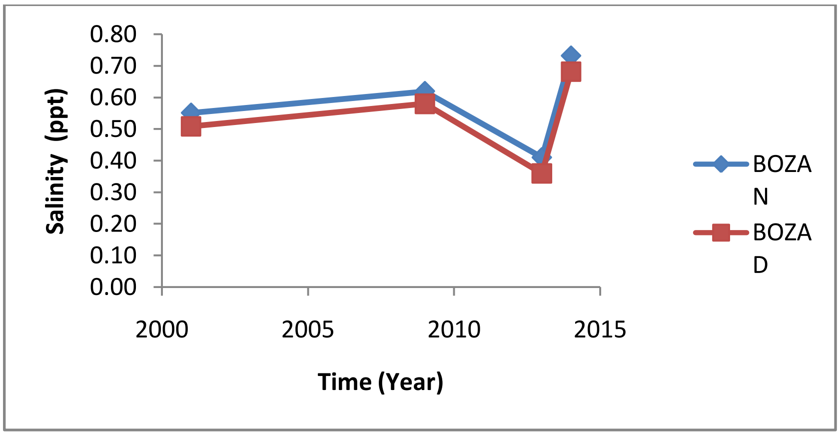


*Figure 4.3: Salinity variation*

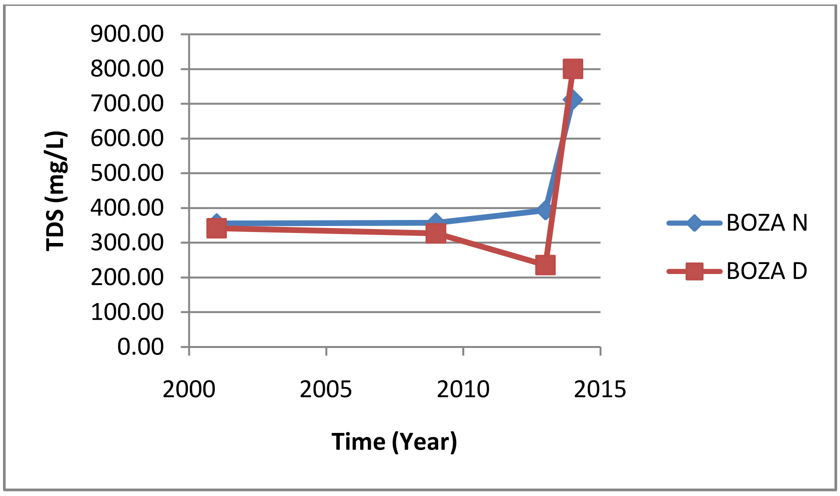


*Figure 4.4: Total Dissolved Solids variations*

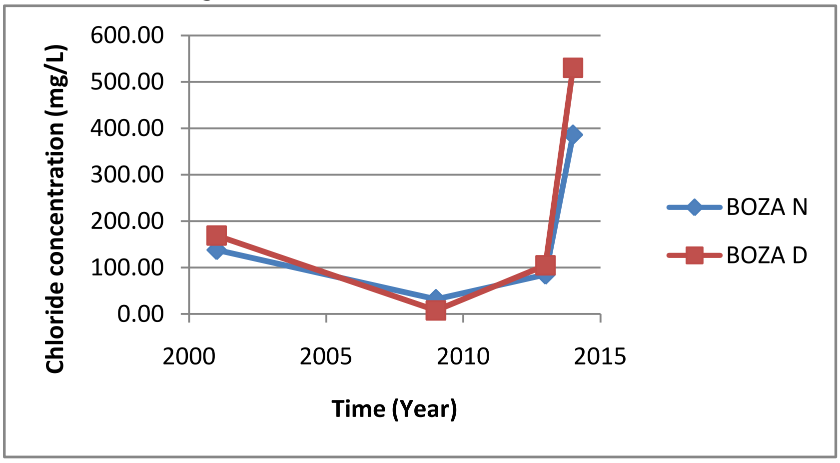


*Figure 4.5: Chloride variation*

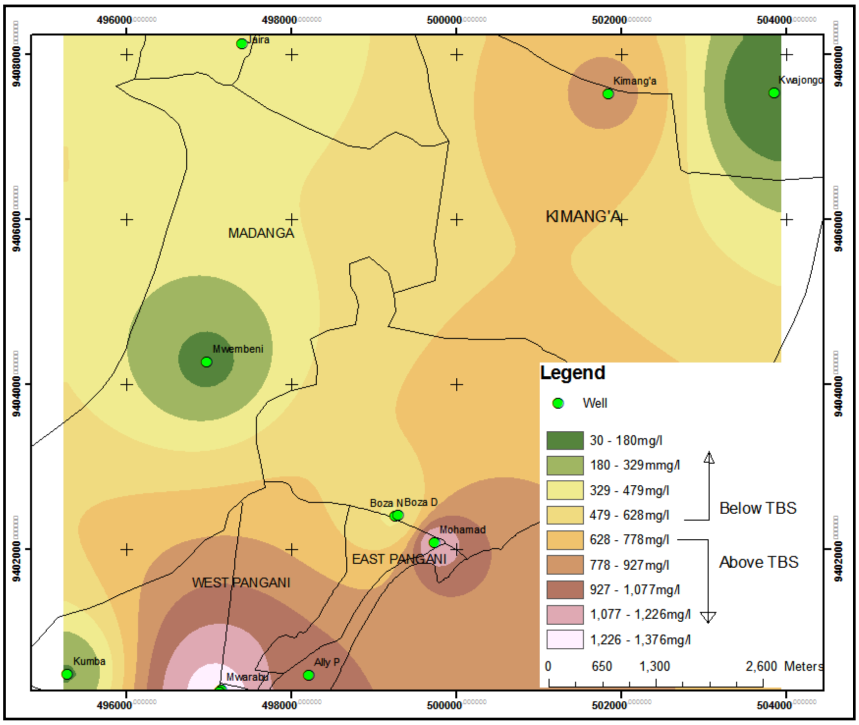


*Figure 4.6: Spatial distribution of Chloride concentration*

**4.2.2. Chemical quality of groundwater**

Three wells out of seven had sodium concentration above 100mg/L with the highest concentration obtained at Police well with 361.01mg Na/L and the remaining wells had concentration below 100mg/L and the lowest concentration was detected at Kwajongo with 43.25mg Na/L. Furthermore, the same wells happened to represent wells with chloride concentration above and below 800mg/L. The highest chloride concentration was 1509.02mg/L and the lowest concentration was 29.4mg/L. 90.91% of the selected wells showed deterioration in water quality due to chloride which exceeds one hundred milligram per litre as shown in figure 4.6 and the possible source being seawater intrusion or sanitary waste.

With regard to calcium concentration, only Police well had concentration of 301.18 mg/l which is above Tanzanian Standards (300mg/L), five wells had concentration above WHO standards (75mg/L) and only one well (Mwembeni) had concentration below WHO Standard (44.8 mg/L) [12, 13]. This implies that Pangani water is hard water and this correlate to interview results whereby 80 % of population responded that water is hard and has taste. Presence of calcium was also observed on storage tanks as whitish strips (plate 4.2).Comparison of major Cations and Anions is provided in figure 4.7.

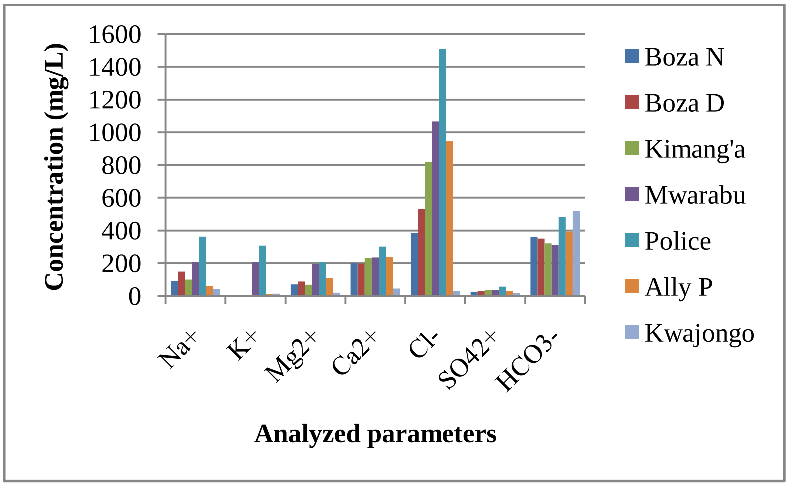


*Figure 4.7: Comparison of major Cations and Anions of selected Wells*

*Plate 4.2: Whitish strips formed due to presence of Calcium in water at Pangani*

**4.3. Salinity potential sources identification**

Based on historical water quality data of three years 2001, 2009 and 2013 which were obtained from Tanga water laboratory and analysis conducted at Ardhi University laboratory in year 2014 (Table 4.2) all samples revealed low concentration of nitrate, phosphate and ammonium (figure 4.8) that allowed minimal suspect of sanitary wastes to be the source of salinity at Pangani aquifer.

**Table 4.2:** Historical water quality data

| Parameters | Salinity ppm | Cl- mg/L | NO3-N mg/L | PO4- mg/L | NH4-N mg/L |
|---|---|---|---|---|---|
| BOZA N (**26/6/2013**) | 0.41 | 85.00 | 3.54 | 0.11 | 1.03 |
| BOZA D (**26/6/2013**) | 0.36 | 105.00 | 2.50 | 0.06 | 0.77 |
| Kumba (**26/6/2013**) | 0.51 | 169.00 | 2.11 | 0.85 | 1.02 |
| Jaira (**26/6/2013**) | 0.49 | 360.00 | 4.04 | 0.21 | 0.98 |
| BOZA N (**24/8/2009**) | 0.62 | 32.00 | 1.80 | 0.30 | 0.52 |
| BOZA D (**24/8/2009**) | 0.58 | 8.00 | 2.30 | 1.04 | 0.67 |
| BOZA N (**10/6/2001**) | 0.55 | 138.00 | 1.30 | 0.24 | 0.38 |
| BOZA D (**10/6/2001**) | 0.56 | 185.90 | 1.87 | 0.94 | 0.55 |
| BOZA N (**2014**) | 0.73 | 386.20 | 2.12 | 0.19 | 0.19 |
| BOZA D (**2014**) | 0.68 | 530.08 | 2.72 | 0.20 | 0.19 |

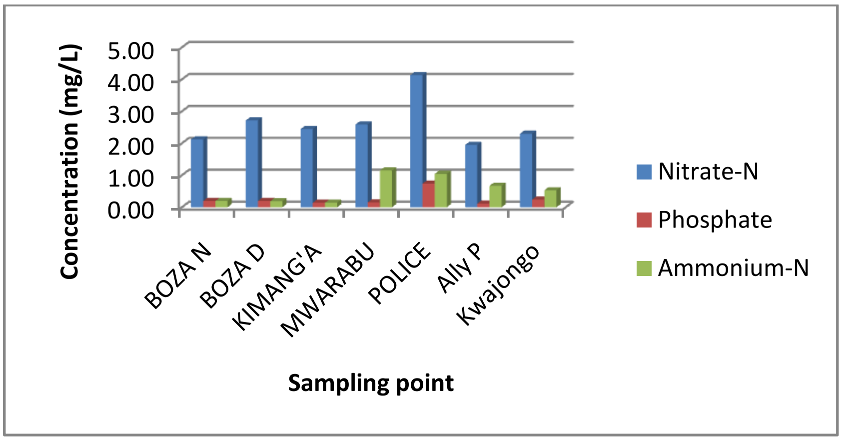


*Figure 4.8: Comparison Nitrate, Ammonium and Phosphate of wells*

The next suspicious source of salinity into groundwater especially in coastal area is seawater intrusion. The probable seawater intrusion into groundwater at Pangani aquifer was recognized using piper diagram as analyzed by AquaChem computer based software.

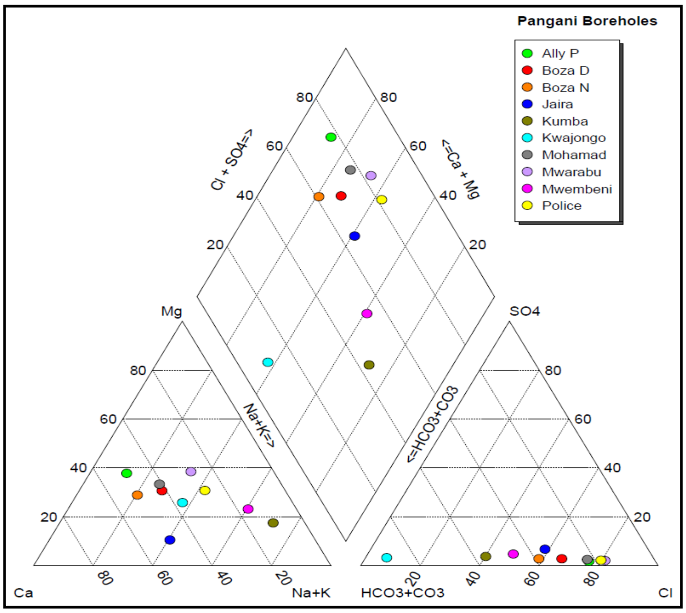


*Figure 4.9: Piper plot presenting seawater intrusion*

AquaChem model described groundwater quality in relation to seawater intrusion in which its main inputs were the major cations ($Na^+$, $Ca^{2+}$ , $Mg^{2+}$ and $K^+$) and major anions ($Cl^-$, $SO_4^{2-}$ and $HCO_3^-$). The Piper diagram for selected wells as analyzed by AquaChem model is as presented in figure 4.9

With respect to Piper diagram presented in figure 4.9, it shows that 70% of the analyzed wells appeared above freshwater and seawater mixing line in the diamond cell, the cell is further divided into four segments namely intrusion, slightly intrusion, fresh, conservative mixing and slightly conservative mixing. Out of the 70% wells, 57% appeared in intrusion segment meaning that their salinity is totally due to sea water intrusion whereas 43% of the wells appeared to be slightly intruded by seawater. In category slightly intrusion by seawater there exist the two wells (Boza N and Boza D) managed by PAWASA. Their depths are about 54m in an elevation of about 35m above mean sea level with average pumping rate of about 18 $m^3$/hr each.The cause of seawater intrusion is due to both over pumping and rise in seawater level as some of the wells their depth is less than 35m in the elevation of < 29m above mean sea level.

The remaining 30% of the wells showed response in the Piper diagram being below the mixing line of which they appeared to be in conservative mixing and slightly conservative mixing meaning that there is an intermittent mixing of fresh water with seawater. The intermittent mixing is subjective to the rate of groundwater extraction which is influenced by population water demand. When there is over abstraction of groundwater, seawater may intrude into freshwater because when pumping groundwater, the seawater rises 40 feet for every 1 foot of freshwater depression and therefore seawater may eventually enter a well that was once pumping fresh water, making it unusable [14, 15].

### 4.4. Groundwater classification at Pangani

Results imported into AquaChem model show that the wells were highly mineralized with calcium, magnesium and Sodium as major cations and with chloride and bicarbonate as major anions, therefore, the water type is Ca-Mg-Na-Cl-$HCO_3$ (table 4.3). This type of water is typical natural saline water which naturally deteriorates by ion exchange within the aquifer. The chemical analysis shows a higher salt content with low amount of soluble sulphate which resulted from dissolution process between water and the minerals.

**Table 4.3:** Water Classification based on Cations-Anions Precedence

| Sampling Point | Water type |
|---|---|
| Ally P | Ca-Mg-Cl-$HCO_3$ |
| Boza D | Ca-Mg-Na-Cl-$HCO_3$ |
| Boza N | Ca-Mg-Na-Cl-$HCO_3$ |
| Jaira | Ca-Na-Cl-$HCO_3$ |
| Kumba | K-Mg-$HCO_3$-Cl |
| Kwajongo | Ca-Na-$HCO_3$ |
| Mohamad | Ca-Mg-Cl-$HCO_3$ |
| Mwarabu | Mg-Ca-Na-Cl |
| Mwembeni | K-Mg-Na-Cl-$HCO_3$ |
| Police | Mg-Na-Ca-Cl |

### 4.5. Proposed Engineering Solution for handling salinity in Pangani

Since Pangani salinity case is associated to seawater rise, its mitigation measures basing on engineering delivery are provision of embankment barriers, desalination by nanotechnology, and modification of pumping pattern - reduce pumping rates as well as change locations of source of groundwater.

#### 4.5.1. Provision of embankment Barrier

A measure requires construction of impermeable subsurface barrier parallel to the coast and it aims at blocking the movement of saltwater from sea to freshwater zone. The barriers to be constructed are slurry walls, bio-walls, grout cut-offs and steel sheet piles.

#### 4.5.2. Application of Nano-filtration for desalination

Water characterized by having high degree of hardness, TDS and high salinity, these properties give rise to major problems such as scaling, fouling, high-energy and high quality construction materials requirements. To solve water desalination problems and to minimize their effects on productivity water cost of conventional plants (figure 4.8), a Nano-filtration (NF) membrane is recommended to be used. The membrane works similar to reverse osmosis except that with NF, less pressure is needed (70 and 140 psi) because of larger membrane pore size (0.05μm to 0.005μm). Nano-filtration can remove some total dissolved solids, but is often used to partially soften water and is successful at removing solids, as well as dissolved organic carbon. This membrane can be employed in pretreatment facilities before water is supplied to the community. Selection of the size of filter is influenced by three factors namely pressure, amount of pumped water and TDS.

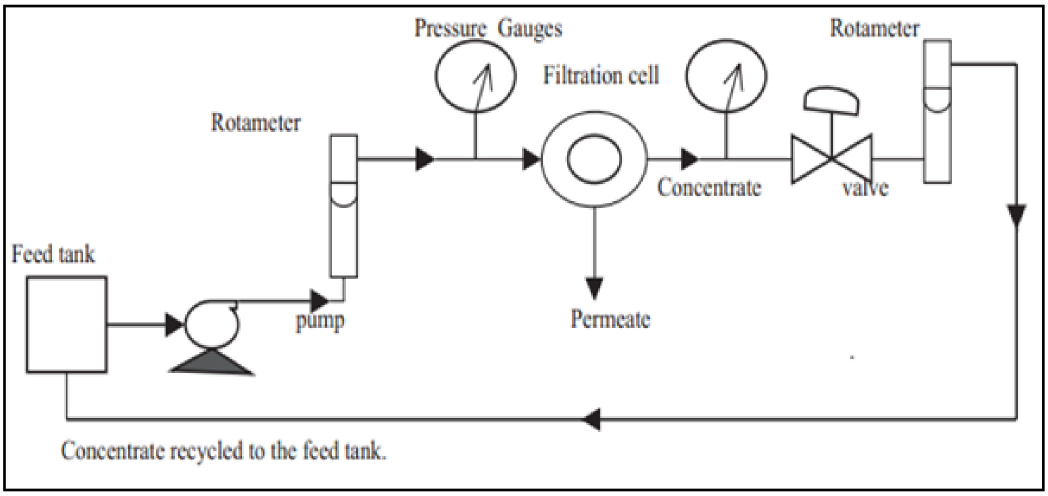


*Figure 4.10: Schematic presentation of Nano-filtration process for desalination*

### 4.5.3. Change Locations of Source of Groundwater

This involves drilling another well in a new location l.

## 5. Conclusion

Water to be supplied to any community should have appreciable physical, chemical and biological quality. The physical-chemical characteristics of the Pangani groundwater indicates that some parameters are within drinking water standards (national and International) and some are not. The significant problematic parameter in Pangani wells is salinity.

Following the completion of the research, below are the conclusions.

i. 100% of the population in Pangani depends on groundwater sources such that More than 80% of the people depend solely for domestic purposes.
ii. Almost all boreholes sampled in Pangani Township showed very high Salinity indicating high level of saltwater intrusion. More than 18% of the wells have brackish water which implies that people in Pangani has no access to portable water as per Tanzania standards.
iii. From piper diagram analysis it has been concluded that more than 73% of the boreholes have high salt due saltwater intrusion influenced by rise of sea water level.
iv. To curb the situation the following has been suggested; more exploration for freshwater boreholes, use of Nano-filtration techniques and change the water source to surface water since Pangani Town is located along River Pangani Basin.

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