Low Water Pollution of Valley Bottom Irrigated Rice in West Africa Case of the Boulbi in Burkina Faso

Amadou KEITA (amadou.keita@2ie-edu.org)
International Institute for Water and Environmental Engineering https://orcid.org/0000-0003-0257-7412
Maanou Rosella Axiane MANTORO
International Institute for Water and Environmental Engineering
Dial NIANG
International Institute for Water and Environmental Engineering
Delphine Aissata BAMA
World Bank Institute

Research Article

Keywords: Burkina Faso, chemicals, GIS, groundwater, pollution, vulnerability

Posted Date: June 1st, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1659398/v1

Abstract

Agricultural inputs are considered as important source of water pollution. This study investigates the situation in the case of the 85 ha Boulbi valley bottom irrigated rice scheme in Burkina Faso, West Africa. Soil hydraulic conductivities and texture were obtained using double-ring infiltrometer and Harmonized World Soil Database. Groundwater recharge was assessed by Thornthwaite's equation. The DRASTIC, GOD and SI methods were applied to map the valley's vulnerability. Fertilizers and phytochemicals were also recorded by individual surveys. A sampling of surface and groundwater was done in 32 locations and the chemical characteristics (pH, EC, NO_3^-, SO_4^{2-}, PO_4^{2-} and K^+) confronted with the vulnerability indices. The soils are predominantly clay (41%), silt (37%) and silty-sand (22%). Twenty types of phytochemicals are used, among which 35% are composed of the controversial glyphosate (denounced as carcinogenic) and 30% made with paraquat chloride also accused of being responsible for magnesium and potassium depletion in soils. All the three methods pointed to a low vulnerability risk, partly because of the epuration role of clay. The SI values (57.5 to 60.0) agreed with the laboratory analysis of NO^{3-} concentration in the groundwater for the 11 locations for which all values were below 50 mg/l, the maximum defined by WHO. The average pH value is 8.2 ± 0.4. This may partly explain the low rice yield (less than 4.0 tons/ha) observed in Boulbi, in spite of fertilizers' application. Although the risk assessment rendered non-alarming situation, preventive measures about health and environmental threats are necessary for raising awareness among the population.

Introduction

Water is a vital, complex and fragile medium for mankind, supporting multiple needs, among which one can mention food, domestic, industries and agriculture. The demographic growth and an often uncontrolled management of water resources lead to a stressing situation, as regards both quantity and quality (Lawani et al. 2017). Aquifers (groundwater) is often object of contamination in relation to the use of chemicals (Tonle and Temgoua 2019). In effect, the prodigious rise of the chemical industry in the 20th century has deeply changed the ways of production and consumption all around the globe; more particularly the shift into massive production and the widespread use of chemicals in agriculture. The use of mineral fertilizers and chemicals have made possible agriculture intensification with a spectacular increase in crop yields (Gbenonchi 2008). In this context, and given the need for effective and efficient methods to protect groundwater resources from future contamination, scientists and resource managers have sought to develop aquifer vulnerability assessment techniques to predict areas which are more likely than others to be contaminated as a result of activity at or near the soil surface (NRC 1993). They can be divided into three main categories: statistical methods, simulation methods and index cartography methods. The last two methods, known as "indexing" methods, are the most often applied and are considered to be the most useful in relation to the realities of the field (Knout et al. 2016). Thus, vulnerability maps illustrate the potential threat of contaminants to groundwater, and may be involved as tools in land use planning and associated important regulations (Saidi et al. 2010). In karstic areas, characterized by preferential infiltration conditions, these maps are also excellent tools for protecting springs and resources (Neukum et al. 2008). One of the standard groundwater vulnerability methods used during this study is DRASTIC (index cartography method). This method considers seven parameters of the geological and hydrological environments. The second index cartography method used – GOD – is like the previous one, but it uses only three parameters. And, finally, the SI (also an index cartography method), targets specific vertical (infiltration) vulnerability and uses five parameters ; it takes into consideration the pollutants of agricultural origin, namely, nitrates and pesticides (Murat et al. 2003). Thus, the general objective of this study is to carry out a comparative analysis of the vulnerability of the water resource – through the use of agricultural inputs – in order to know the current state of pollution on the peri-urban rice-growing valley bottom of Boulbi, located 25 kilometers from Ouagadougou, the capital of Burkina Faso in West Africa (Fig. 1). To achieve this objective, a soil characterization and a physicochemical analysis of surface and groundwater in the Boulbi valley were carried out in order to establish the state of pollution related to the use of chemical fertilizers. The present investigation is justified by the presence of knowledge gap of case studies about agrochemical pollution in small farms around big cities in Sahelian countries.

Material & Methods

Presentation of the Study Area

The irrigated rice-growing valley bottom of Boulbi (Fig. 2) – located in the central region of Burkina Faso (latitude 12°14'01.63"N and longitude – 1°31'52.33"W) at about 25 km from Ouagadougou on National Road No. 6 – covers a total area of 85 ha of which 75 ha are sown land and divided into seven blocks. It was developed in 1960 mainly for rice production by Taiwan. The study area is covered by a tropical climate of the Sudano-Sahelian type (600 mm to 900 mm of rainfall per year). The hydrographic network of the study area is part of the Nariarlé sub-basin, which has an area of about 1000 km^2 and is an important watercourse that joins the Massili River to flow into the Nakambe River on the left bank (Moiroux 2006). The topography is marked by altitudes between 280 m and 300 m, with three main morphological units: a functional glacis, a battleship level offering opportunity for road construction, and the lowlands and water bodies that offer opportunities for agricultural development. The geology of the study area is represented by a crystalline complex of Precambrian D age Antebirrimian (Iwaco 1993). The basement zone aquifer consists of three overlying aquifer systems, which are from bottom to top: fractured media aquifers; altered zone aquifers and laterite aquifers.

Soil Hydrodynamic Parameters

Infiltration measurements were performed in situ in May 2020, and yielded the infiltration rates. Infiltrations measured by the double ring method are not very sensitive to the textural heterogeneity stratification of soils (Mbilou 2016). The two rings are staffed concentrically, using a plank and a hammer, to a depth of about 5 cm in the ground. The principle is to follow the evolution of the water level as a function of time in the central ring (Keita 2020). During this measurement campaign, a total of 22 measurement points was carried out, selected to cover the entire valley bottom. The data were processed with the statistical software, Minitab 18, by applying a non-linear regression to the accumulated infiltration data to determine the saturated hydraulic conductivity (K_{sat}). The double ring permeabilities (K_{sat}) – in combination with date provided by the Harmonized World Soil Database (HWSD) (Nachtergaele et al. 2012) – were then entered into the Soil Water Characteristics (SWC) software to determine the characteristic soil moistures (Saxton et al. 1986). The available moisture (AM) retained on the valley bottom is the average of those derived from the K_{sat} readings on SWC, when the values of these have a coefficient of variation lower than 20%.

Groundwater Resource Assessment

The recharge of aquifers by rainfall is subject to very large variations on a regional or national scale. At a given site, recharge also varies considerably from one year to the next under the influence of interannual climatic fluctuations. The evaluation of natural groundwater recharge has always been very difficult. Various techniques have been classically considered to achieve this, often requiring sophisticated and expensive equipment at the observation sites. Among these, the methods closest to direct measurements, evaluating recharge by simple difference between terms of the water balance, are called climatic (Fillipi et al. 1990). All the methods used are based on different hypotheses and each is accompanied by uncertainty (Dara 2017). Thornthwaite's method is the only one that allows the expression of potential evapotranspiration (ETP) with easily accessible parameters: the average temperature of the air under shelter (atmospheric data) and the theoretical duration of insolation (astronomical data, a function of the season and latitude). It is given by the equation Eq. 1:

$ETP = 16 \cdot (10 \cdot t \cdot I) \cdot a \cdot f(\varphi)$ Eq. 1

With:

– $I = \sum (t/)^{1.51412}$

- *t*: average air temperature of the period considered;
- *I*: annual thermal index, is the sum of twelve-monthly indices;
- *f (φ)*: corrective term depending on the theoretical duration of insolation, the latitude and the month;
- *a*: complex function of the index I. $a = 0.016 \cdot I + 0.5$

Methods for Mapping Pollution Vulnerability

There is no absolute method for assessing the vulnerability of groundwater, but several methods for estimating the sensitivity of aquifers to pollution have been developed (Murat 2000). In the present study, three methods are applied: DRASTIC (Aller et al. 1987); GOD (Foster and Hirata 1991) and SI (Ribeiro 2000), and the results will be confirmed or refuted by chemical analysis in the laboratory.

- The acronym DRASTIC (Aller et al. 1987) represents the seven P_x parameters used in the method which are: depth to water table (*D*), the net recharge (*R*), the type of aquifer (*A*), the soil type (*S*), the topography (T), the vadose zone (unsaturated area above water table) impact (I), and hydraulic conductivity (C). The method produces a numerical index that is derived from the *ratings* (r) and *weights* (w) assigned to the seven method parameters (Alwarhaf and El Mansouri 2011). The expression is given by Eq. 2:

$$I_{DRASTIC} = D_w \cdot D_r + R_w \cdot R_r + A_w \cdot A_r + S_w \cdot S_r + T_w \cdot T_r + I_w \cdot I_r + C_w \cdot C_r \quad \text{Eq. 2}$$

- The GOD method (Foster and Hirata 1991) also uses an empirical approach where aquifer vulnerability is defined in terms of the inaccessibility of the saturated zone, in the sense of pollutant penetration, and the attenuation capacity of the layer above the saturated zone, i.e., it presents the vulnerability of the aquifer to vertical percolation of pollutants through the unsaturated zone and does not address lateral migration of pollutants into the saturated zone (Bouselsal et al. 2015). The three parameters used are: i) the identification of the type of aquifer in terms of its degree of confinement (C_i); ii) the depth to the water table (C_p) and iii) the characteristics of the layers overlying the saturated zone of the aquifer in terms of their relative porosity, permeability and water content (C_a). The vulnerability index (I_{GOD}) is obtained by Eq. 3:

$$I_{GOD} = C_i \cdot C_p \cdot C_a \quad \text{Eq. 3}$$

- The SI (susceptibility index) method is a specific vertical vulnerability method developed by taking into account the behavior of pollutants of agricultural origin, mainly nitrates and pesticides (Ribeiro 2000). It uses five parameters: Water table depth (D), Net recharge (R), lithological nature of the Aquifer (A), Topography of the land (T), and Land use (O). The vulnerability index SI is obtained by calculating the vulnerability index (I_{SI}) by the equation Eq. 4:

$$I_{SI} = D_c \cdot D_p + R_c \cdot R_p + A_c \cdot A_p + T_c \cdot T_p + O_c \cdot O_p \quad \text{Eq. 4}$$

Parameters Assessment and Vulnerability Levels

The quality of the vulnerability maps depends, among other things, on the data and the processing to which they have been subjected (Ake et al. 2010). Thus, a careful review of the data must be conducted to highlight the available information and its quality. In the case of this study, the integration of the results of the field work conducted during the period of April 2020 to January 2021 has complemented the knowledge of the territory that the compilation of existing data had allowed. The available datasets are of point, vector and raster types. In order to apply the vulnerability assessment methods, the goal of the data processing is to transform the point and vector data into raster data and to standardize the format of the raster data (Ake et al. 2010). The "depth to water table" parameter was evaluated by interpolating water level data collected from large diameter wells on the valley bottom. This treatment involves little data manipulation, which limits the multiplication of errors. For the "topography" parameter, a raster map of the percentage of slope is made from the digital terrain method and the slope values are assigned to the pixels according to the vulnerability method rating system. The "soil type" parameter is obtained by listing the different soil types according to the defined soil classes. In the absence of a perfect match between a map unit and a soil class, a rating is assigned by deduction (Kimmeier 2001). The elaboration of the vulnerability maps for the three methods was done with ArcGIS (Fig. 2).

Validation of Vulnerability Maps

In general, the development of a vulnerability map to agricultural pollution is validated by field measurements and chemical analysis of the water. Several authors (Mohamed, 2001; Jourda et al., 2007) tested the validity of the pollution vulnerability assessment methods based on groundwater chemistry data. The validity of the water pollution assessment by the DRASTIC, GOD and SI methods was tested by measuring the pollution of nitrate levels in the water. The results obtained are raster maps whose value ranges correspond to those of the ratings defined for each parameter.

Inventory of Agricultural Inputs

The inventory of agricultural inputs was made in the form of a survey administered to 30 farmers spread over the entire valley bottom of Boulbi, during the month of August 2020. The purpose of these surveys – administered in individual form – was to list the different types of plant protection products and chemical fertilizers used on the plain, as well as the quantities applied per campaign.

Water Sampling and Physicochemical Analysis

In order to carry out the inventory of pollution in the study area, 32 water samples were taken at various points on the valley: in wells, in drains, in plots and at the dam. For each sampling point, three 0.5-liter samples of water were taken, using 0.5-liter plastic bottles that had been rinsed three times with the water to be sampled. The aim was to determine the values of physical parameters such as pH and electrical conductivity, but also to characterize the quality of the water through chemical analysis by determining the concentrations of nitrate, phosphate, sulphate and potassium ions.

Sensitive physical parameters such as hydrogen potential (pH) and electrical conductivity (EC), which can easily change during transportation, were measured in situ on the unfiltered samples using a 3310 WTW handset 2 pH-meter and a 3310 WTW handset, a conductivity meter. Before the chemical parameters' measurements, a vacuum pump and a GFC filter were used for the samples pre-treatment. Sulphate (SO_4^{2-}), nitrate (NO_3^{-}), phosphorus(PO_4^{2-}) ions concentrations were determined by molecular absorption spectrometry (direct Reading DR 3900) (Hach 2020), and potassium (K^+) is determined by flame spectrometry (Adouani 2020).

Results And Discussions

Infiltration Measurement: Permeability and Available Moisture

The measured permeabilities (K_{sat}), introduced in the Soil Water Characteristics (SWC) software (Saxton et al. 1986) for the determination of the characteristic soil moisture, allowed to obtain, in combination with HWSD (Nachtergaele et al. 2012), several soil textures for the same permeability but with almost equal available moisture (*AM*) for the obtained soil textures. The different textures obtained on SWC, were clay-silt texture covering 41% of the valley area (which can also correspond to the clay), clay-silt, clay-sand or loamy-clay-sand texture, with an *AM* of 12.22 ± 1.9. The silty texture covers 37% of the valley bottom area, and can correspond to the following textures: loamy-sandy-clay, loamy-silty, loamy with an average *AM* of 3.06 ± 0.02. Finally, the soils of silty-sandy texture cover 22% of the valley bottom area, but also fits the following textures: sandy-loamy and silty-loamy with an average *AM* of 13.2 ± 4.10.

Variability of the Water Table During the Year

The recharge of the aquifer calculated by the Thornthwaite balance is equal to 68.48 mm, i.e. 7% of the rainfall. It is higher than the values found for the altered aquifers in the Ouagadougou area, ranging from 19.95 to 49.88 mm/year (Hie 2009), which can be explained by a higher value of the runoff coefficient. In fact, in irrigated rice field such as in Boulbi valley bottom, the use of delineation dikes of farm plots decreases runoff and subserve infiltration.

Agricultural Input Inventory

The survey provided an overview of the types of treatments applied by rice farmers in the study area. The most frequent treatments were herbicides, due to the quantity of weeds, and insecticide, due to crop pests. This situation fits with that described generally in Burkina Faso (Toe 2007). The different types of inputs used on the Boulbi valley bottom are NPK (14-23-14) and urea. Organic manure use is very rare on the plain mainly due to its high cost. Twenty (20) types of phytosanitary products are used on the irrigation scheme Table 1, among which 35% are composed with the controversial glyphosate (Lajmanovich et al. 2015; Sarkar and Das 2017). Several studies indicate glyphosate to be a highly toxic and carcinogenic substance. It is also interesting to note that paraquat chloride – denounced to be responsible for magnesium and potassium depletion in soils (Mbuk et al. 2009) – represents 30% of the herbicides used. The World Health Organization recommends that the use of these products be reserved for trained persons who respect the precautions required (Gougo 2016).

Table 1
List of phytosanitary products used on the Boulbi valley bottom

TRADE NAME	PESTICIDE TYPE	ACTIVE SUBSTANCE
ADWURA WURA	Herbicide	GLYPHOSATE 360 g/l
ADOPA WURA	Herbicide	GLYPHOSATE 360 g/l
BIBANA	Herbicide	GLYPHOSATE 360 g/l
GROWNSATE	Herbicide	GLYPHOSATE 480 g/l
GANORSATE	Herbicide	GLYPHOSATE 480 g/l
SUNPHOSPHATE	Herbicide	GLYPHOSATE 350 g/l
ROUNDUP 360 SL	Herbicide	GLYPHOSATE 360 g/l
BENAXONE SUPER	Herbicide	PARAQUAT CHLORIDE 276 g/l
GRAMOQUAT SUPER	Herbicide	PARAQUAT CHLORIDE 276 g/l
GRAMOSHARP SUPER	Herbicide	PARAQUAT CHLORIDE 276 g/l
GRAMODA SUPER	Herbicide	PARAQUAT CHLORIDE 276 g/l
GRAMOKING 276 SL	Herbicide	PARAQUAT CHLORIDE 276 g/l
PARAKIN 276 SL	Herbicide	PARAQUAT CHLORIDE 276 g/l
EMACOT	Insecticide	EMAMECTINE BENZOATE
KAPAASE	Insecticide	EMAMECTINE BENZOATE 20 g/l; ABAMECTINE 20 g/l; ACETAMIPRIDE 40 g/l
DECIS 25 EC	Insecticide	DELTAMETHRINE 25 g/l
ALLIGATOR 400 EC	Herbicide	PENDIMETHALINE 400 g/l
PYRICAL	Insecticide	CHLOPYRIPHOS-ETHYL
SAMORY	Herbicide	BENSULFURON METHYL 100 g/kg
TOROL	Insecticide	LAMBDACYHALOTHRINE 16 g/l

Analysis of method parameters

In general, the water table is shallow, with static levels varying from 2.22 m to 3.55 m (Table 2), thus assigning high elevation values to the parameter *D* in all the three methods. Net recharge (*R*) on the Boulbi plain is low, averaging 68.48 mm/year. The Boulbi rice plain has a free water table. Analysis of the logs of boreholes drilled in the area (Ouandaogo/Yameogo 2008) shows that the lithological nature of the Aquifer (*A*) is composed of alluvial deposits, essentially clay and granite. The type of soil (*S*) in place are essentially clay, clay loam and loamy sand. The calculated slopes (topography parameter *T*) give very low values, ranging from 0.0 to 4.0%. The vadose zone impact (*I*) class include mainly clay, metamorphic and igneous rocks. The permeability test using double rings has made it possible to determine the hydraulic conductivity (*C*) of the soils. The plain is essentially an agricultural area (land use parameter *O*) with irrigated rice fields, irrigated vegetables and plantations (only the SI method is concerned by this parameter).

Table 2
Rating (*r*) values obtained for each parameter in the 3 vulnerability methods

Rating (r) computed for the three vulnerability methods				
Parameter	Class	DRASTIC	GOD	SI
Water table *D* (m)	2,22 – 3,55	9	1	90
Recharge *R* (mm/an)	68,48	3	-	30
Lithology *A*	Free water table/fractured granite	3	0,7	30
Type of sol *S*	Laterite	3	-	-
	Clay	1	-	-
	Clay loam	4	-	-
	Loamy sand	6	-	-
Topo slope *T*(%)	0–2%	10	-	100
	2–4%	9	-	90
Vadose *I*	Clay,	3	0,55	-
	Metamorphic and igneous rock	1	0,60	-
Conductivity *C* (m/s)	1,5.10-7–5.10-5	1	-	-
	5.10-5–15.10-5	2	-	-
Land use O	rice, irrigated vegetables, plantations	-	-	90

Vulnerability Characterization

A class of low vulnerability occupying the entire surface of the plain, with indices oscillating between 83 and 88, shows on the map of the vulnerability to agricultural pollution by the DRASTIC method (Fig. 3) indicating that the plain is more likely well protected. The nature of the dominant soil with a very high clay content is a factor limiting the infiltration of pollutants into the aquifer, hence the relatively low vulnerability class. The figure yielded by the GOD method also shows moderate vulnerability class (Fig. 4): it extends over the entire study area with indices between 0.35 and 0.42. It guarantees a less severe pollution in case of contamination. This degree of medium vulnerability may be related to the nature of the vadose zone, essentially composed of clay and granite, and the dominant soil on the plain, composed of clay, which is not very permeable (Khakhar et al. 2017). Finally, the SI method, gives values that vary between 57.5 and 60 (Fig. 5). The analysis of this map highlights a class of medium vulnerability, which occupies the entire plain. These vulnerability indices guarantee a less severe pollution in case of contamination. The results of SI map were in agreement with the laboratory analysis of NO_3^- concentration in the groundwater for the entire 11 locations (Fig. 7) for which all the values were found below 50 mg/l, the maximum defined by WHO (Hamza et al. 2007; Stigter et al. 2006; Ward et al. 2018). However, it should be noted that the results of the validation of the vulnerability maps could be more complete if a larger number of nitrate measurements well distributed over the surface of the studied aquifer were carried out, as the data only concerned the water from wells present on the plain.

Determination of the physico-chemical characteristics of the collected water

The parameters measured in the field concerned 32 samples, 21 of which were from surface water (plots of land, earthen drains, and in the dam) and 11 for water from large diameter wells present on the plain.

Hydrogen potential

The surface water in the Boulbi valley bottom, at the level of the plots, the drains and the irrigation dam are clearly basic. The average pH value is 8.2 ± 0.4. The well groundwater on the plain is slightly basic, even close to neutrality with an average pH of 7.3 ± 0.24 (Fig. 6). Though unclear, attempts have been made to explain why a lake or dam irrigation water tends to be basic. The reduction of sulphate in dam water seems to contribute to the formation of carbon dioxide CO_2 which reacts with hydroxide anion OH^- to form HCO^{3-} and CO_3^{2-}, thus increasing the water basicity (Borzenko et al. 2018). It should be noted that the pH of the irrigation water should be between 5.5 and 6.5 for better micronutrient absorption and improved photosynthesis and yield of the crops (Guimarães et al. 2021; Liu et al. 2016). This basic pH may partly explain the low rice yield (less than 4.0 tons/ha) observed in Boulbi valley bottom in spite of the use of fertilizers. The pH values measured for Boulbi waters comply with the WHO recommendations (Ward et al. 2018) for drinking water (6.5–8.5). Additionally, it can be noted that the pH values found are slightly higher than the values found by Ouandaogo (2008) in the waters of Ouagadougou. Finally, other authors found values of 6 to 8.5 in surface waters in sub-Saharan Africa (Abai et al. 2014; Chapman and Kimstach 1996), more in agreement with those of Boulbi.

Electrical Conductivity and Nitrates

The average conductivity is higher for groundwater (195.6 ± 42.2) µs/cm than for surface water (156.9 ± 12.4) µs/cm. These conductivity values are too low to be able to cause any damage to rice. The waters (ground and surface water) are moderately mineralized as they are in the range of (150 to 300) µs/cm (Ferreira et al. 2019). It is known that the conductivity values of surface waters change according to the geological structure and the amount of precipitation (Tepe and Boyd 2003). High EC values indicate the presence of a high concentration of dissolved salts in the water and also correspond to local or point source groundwater pollution during rainy periods.

Nitrate testing in water is a good indicator of raw water quality, and in the long-term nitrate contamination can generally lead to eutrophication of surface waters due to excessive nutrient and biodegradable matter inputs. Nitrate values vary significantly from surface water (4.29 ± 2.25) mg/l to well water (15.61 ± 10.36) mg/l. The values obtained show higher nitrate concentrations in well water which are mainly due to irrigation water running into not-coping protected wells, fish farming, pastoral activities and runoff around and in the Boulbi valley bottom (Fig. 7). These nitrate values are lower than WHO guidelines for surface waters (50 m g/l). Studies conducted by Some (2008) and Tapsoba (2016) also report concentrations lower than the WHO standards for surface water in the Nakambé basin in Burkina Faso, and in dams N°3 of Ouagadougou and DEBE respectively of 34 m g/l; 6.6 m g/l and 9.2 m g/l.

The O-Phosphates (PO_4^{3-})

Analysis of the results shows very small phosphate concentrations ranging from (0.067 ± 0.02) mg/l to (0.065 ± 0.04) mg/l for groundwater and surface water respectively (Fig. 8). These phosphorus values are significantly lower than the maximum EPA (US – Environmental Protection Agency) tolerated value of 0.1 mg/l and those found in several other countries like South Africa, Brazil, or New Zeeland (Warrack et al. 2021), but are close to those obtained by Tapsoba (2016) at the level of the dam N°3 of Ouagadougou (0.14 m g/l). A study conducted by Hammami et al. (2005) showed that NO_3^- and PO_4^{3-} ions found in surface waters are due to the use of organic fertilizer (organic manure). According to (Zacharia 2002), concentrations of more than 0.5 mg/l and 0.02 mg/l of NO_3^- and PO_4^{3-} respectively in surface waters, indicate pollution levels that may cause eutrophication. In situ observations and the low concentration of less than 0.07 mg/l in surface and groundwater of Boulbi show that eutrophication is not currently a major risk.

Sulphate (SO_4^{2-}) and Potassium K^+

Sulphate levels in the water samples ranged from (0.0 to 3.0) m g/l, with an average of (1.18 ± 1.07) mg/l for groundwater and (0.57 ± 0.7) mg/l for surface water (Fig. 9). These values are lower than the WHO standard limits of 250 mg/l. They are close to those obtained by Ayouba (2015) in the locality of Yamtenga in Burkina Faso, values ranging from (0.0 to 9.0) mg/l. A study conducted in the sub-watershed of Tougou dam by Djibo (2020) showed that sulphate values are higher during rainy periods than those without rain, which can be explained by the variation of the fertilizer dose as the plant grows.

The results of the potassium ion concentration in the samples give an average value of (5.05 ± 1.9) mg/l for surface water against (4.44 ± 1.4) mg/l for well water. These potassium concentration values are below the WHO standard limits (12 mg/l) (Meride and Ayenew 2016). Potassium is generally less abundant in water and does not usually exceed 10 m g/l.

Conclusion

The problems related to water pollution are currently a source of concern that requires universal interest. The case study of the impact of irrigation, pesticides and chemical fertilizers on water quality was well investigated in the Boulbi valley bottom irrigated rice in Burkina Faso. The soils are predominantly clay (41%), silt (37%) and silty-sand (22%). Due to the construction of bunds around rice plots, the annual aquifer recharge of 68.48 mm represents up to 7% of the rainfall. Two (2) types of fertilizers are used in the valley – NPK (14-23-14) and urea 46% – while twenty (20) types of phytosanitary products are used, among which 35% are composed with the controversial glyphosate (denounced to be carcinogenic) and 30% made with paraquat chloride also accused of being responsible for magnesium and potassium depletion in soils. The implementation of groundwater vulnerability mapping allowed easy identification of areas susceptible to potential pollution. All the three methods applied – DRASTIC, GOD and SI – pointed to a low vulnerability risk, partly because of the epuration role of clay formations. For example, DRASTIC provided indices oscillating between 83 and 88, indicating that the plain is more likely well protected. The SI method map values agreed with the laboratory analysis of NO^{3-} concentration in the groundwater for the entire 11 locations for which all the values were found below 50 mg/l, the maximum defined by WHO. The results of the physicochemical analyses revealed that the surface water in the farm plots, the drains and the irrigation dam are clearly basic. The average pH value is 8.2 ± 0.4. This basic pH may partly explain the low rice yield (less than 4.0 tons/ha) observed in Boulbi in spite of the use of fertilizers. Nitrate values vary significantly **from** surface water (4.29 ± 2.25) mg/l **to** well water (15.61 ± 10.36) mg/l. Higher nitrate concentrations in well are mainly due to irrigation water running into not-coping protected wells. However, these nitrate values are lower than WHO guidelines for surface waters (50 mg/l). In situ observations and the low concentration of less than 0.07 mg/l (the US-EPA limits is 0.1 mg/l) in surface and groundwater of Boulbi show eutrophication is not currently a major risk. Sulphate levels in the 32 water samples ranged from (0.0 to 3.0) mg/l, with an average of (1.18 ± 1.07) mg/l for groundwater and (0.57 ± 0.7) mg/l for surface water, values lower than the WHO standard limits of 250 mg/l. the potassium ion concentration in the samples give an average value of (5.05 ± 1.9) mg/l for surface water against (4.44 ± 1.4) mg/l for well water, values also below the WHO standard limits (12 mg/l). Although the risk assessment rendered non-alarming situation, it is necessary to take preventive measures in order to preserve farmers and water resources by raising awareness among the population about health and environmental threats.

Statements & Declarations

The following statements must be included in your submitted manuscript under the heading 'Statements and Declarations'. This should be placed after the References section. Please note that submissions that do not include required statements will be returned as incomplete.

Funding

This work was financially supported by the World Bank through its Excellency Centre in Africa (CEA) of which the International Institute for Water and Environmental Engineering (2iE) is partner.

Competing Interests

“The authors have no relevant financial or non-financial interests to disclose.”

Author Contributions

All authors contributed to the study conception and design. Material preparation and data collection were done by Maanou Rosella Axiane MANTORO and Delphine Aissata BAMA. Data analysis and manuscript writing were performed by Amadou KEITA and Maanou Rosella Axiane MANTORO and Dial NIANG. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

ACKNOWLEDGEMENTS

Authors would like to especially thank Mr. Seth Nii Moi Allotey, a lecturer at the Language Centre, University of Ghana, Legon, for taking time to read and correct this paper.

References

1. Abai EA, Ombolo A, Ngassoum MB, Mbawala A (2014) Suivi de la qualité physico-chimique et bactériologique des eaux des cours d’eau de Ngaoundéré, au Cameroun. Afr Sci Rev Int Sci Technol 10:135–145. https://doi.org/10.4314/afsci.v10i4
2. Adouani I (2020) Cours de chimie analytique: La Spectométrie d’absorption atomique
3. Ake J, Kouadio H, Dongo K, Dibi B, Kouame F, Biemi J (2010) Application des methodes DRASTIC et SI pour l’étude de la vulnérabilité à la pollution par les nitrates de la nappe de Bonoua au sud-est de la Cote d’Ivoire.Int. J. Biol. Chim. Sci.9
4. Aller L, Bennet J, Lehr R, Petty H (1987) DRASTIC: A standardised system for évaluating groundwater pollution potential using hydrogeologic settings.US Environ. Agency EPA641
5. Alwarhaf Y, El Mansouri B (2011) Assessment of Aquifer Vulnerability Based on GIS and ARCGIS Methods: A Case Study of the Sana’a Basin (Yemen). J Water Resour Prot 3:845–855. https://doi.org/10.4236/jwarp.2011.312094
6. Ayouba M, Guel B (2015) Caractérisations physico-chimiques des eaux souterraines de la localité de Yamtenga au Burkina Faso. Int J Biol Chim Sci 9:17

7. Borzenko SV, Zamana LV, Usmanova LI (2018) Basic formation mechanisms of Lake Doroninskoye soda water, East Siberia, Russia. Acta Geochim 37:546–558. https://doi.org/10.1007/s11631-017-0250-7
8. Bouselsal B, Zeddour A, Belksier M, Fenazi B (2015) Contribution de la Méthode de Vulnérabilité Intrinsèque GOD à l’Etude de la Pollution de la Nappe Libre d’Ouargla (SE Algérie). Int J Environ Glob Clim 2:92–99
9. Chapman D, Kimstach V (1996) Water quality assements: a guide to use of biota sediments and water in environmental monitoring. E & FN spon, london, pp 59–126
10. Dara A (2017) Caractérisation des processus de recharge d’un aquifere fracturé enmilieu de socle sous climat sahelien: cas du site de Tougou region du Yatenga au Burkina Faso (Memoire master 2). Institut International de l’Eau et de l’Environnement 2ie, Ouagadougou
11. Djibo H, A (2020) Etude d’impact des activités culturales sur la qualité des eaux du sous bassin barrage de Tougou: caractérisation physico-chimique (Memoire master 2). Institut International de l’Eau et de l’Environnement 2ie, Ouagadougou
12. Ferreira JFS, Liu X, Suarez DL (2019) Fruit yield and survival of five commercial strawberry cultivars under field cultivation and salinity stress. Sci Hortic 243:401–410. https://doi.org/10.1016/j.scienta.2018.07.016
13. Fillipi C, Milville F, Thierry D (1990) Evaluation de la recharge naturelle des aquifères en climat soudano sahelien par modelisation hydrologique globale: application a dix sites.Hydrol. Sci. J.21
14. Foster S, Hirata R (1991) Groundwater pollution risk assessment. A methodology using.Pan Am. Cent. Sanit. Eng. Environ. Sci. CEPIS73
15. Gbenonchi M (2008) Bilan environnementalde l’utilisation des pesticides organochlorés dans les cultures du coton. café et cacao au togo et recherche d’alternatives par l’évolution du pouvoir insecticides d’extraits de plantes locales contre le scolyte du café. (Thèse). Université de Toulousse INP, Toulouse
16. Gougo A (2016) In: Banfora (ed) Burkina Faso) (Memoire master 2). Institut International de l’Eau et de l’Environnement 2ie, Ouagadougou, Etude de la vulnérabilité à la pollution agricole de l’aquifère alluvial de Karfiguela
17. Guimarães JdeJ, de Sousa FGG, Román RMS, Dal Pai A, Rodrigues SA, Sarnighausen VCR (2021) Effect of irrigation water pH on the agronomic development of hops in protected cultivation. Agric Water Manag 253:106924. https://doi.org/10.1016/j.agwat.2021.106924
18. Hach (2020) DOC022.77.90323,DR 3900: Manuel d’utilisation
19. Hammami J, Brahim M, Gueddari M (2005) Essai d’évaluation de la qualite des eaux de ruissellement du bassin versant de la lagune de Bizerte. Inst Natl Sci Technol Mer 32:69–77
20. Hamza MH, Added A, Francés A, Rodríguez R (2007) Validité de l’application des méthodes de vulnérabilité DRASTIC, SINTACS et SI à l’étude de la pollution par les nitrates dans la nappe phréatique de Metline–Ras Jebel–Raf Raf (Nord-Est tunisien). Comptes Rendus Geosci 339:493–505. https://doi.org/10.1016/j.crte.2007.05.003

21. Hie M (2009) Etude géochimique et piézométrique des eaux souterraines de la region de Ouagadougou au Burkina Faso (Memoire master 2). Institut International de l'Eau et de l'Environnement 2ie, Ouagadougou
22. Iwaco (1993) Carte hydrogéologique du BURKINA FASO
23. Jourda J, Kouame J, Adja M, Deh S (2007) Evaluation du degré de protection des eaux souterraines, vulnérabilité à la pollution de la nappe de Bonoua (sud est cote d'ivoire) par la methode DRASTIC. *Actes Conférence Francoph. SIG*, Versailles-France 11
24. Keita A (2020) Micro-aspersion par pompage photovoltaique, Quincaillerie Agro Forestière (QAF). ed 'Les manuels pratiques du developpement durable. Ouagadougou
25. Khakhar M, Ruparelia JP, Vyas A (2017) Assessing groundwater vulnerability using GIS-based DRASTIC model for Ahmedabad district, India. Environ Earth Sci 76:440. https://doi.org/10.1007/s12665-017-6761-z
26. Kimmeier (2001) Geohydrological parameter identification and groundwater vulnerability to pollution
27. Knout N, Boudhar A, Bachaoui E, Afhzaf B (2016) Étude de la vulnérabilité des nappes à la pollution en zones semi-arides: cas de la nappe phréatique des Béni Amir au Maroc. Study of the groundwater vulnerability to pollution in semi-arid areas: the example of Beni Amir aquifer, Morocco. *J. Mediterr. Geogr.*, Ecosystems, Hydrology
28. Lajmanovich RC, Attademo AM, Simoniello MF, Poletta GL, Junges CM, Peltzer PM, Grenón P, Cabagna-Zenklusen MC (2015) Harmful Effects of the Dermal Intake of Commercial Formulations Containing Chlorpyrifos, 2,4-D, and Glyphosate on the Common Toad Rhinella arenarum (Anura: Bufonidae). Water Air Soil Pollut 226:427. https://doi.org/10.1007/s11270-015-2695-9
29. Lawani R, Kelome N, Hounkpe J, Agassounon D, Adjagod (2017) Effects of agricultural practices on the pollution of surface water in Benin republic.Larhyss J.18
30. Liu X, Tao Y, Wen G, Kong F, Zhang X, Hu Z (2016) Influence of Soil and Irrigation Water pH on the Availability of Phosphorus in Struvite Derived from Urine through a Greenhouse Pot Experiment. J Agric Food Chem 64:3324–3329. https://doi.org/10.1021/acs.jafc.6b00021
31. Mbilou U (2016) Mésure de la vitesse d'infiltration des eaux dans le sol: cas des sols de la vallée du NIARI en republique du congo. J Appl Biosci 100:20
32. Mbuk RO, Sha'Ato R 2, Nkpa NN (2009) The Role of Paraquat (1,1-dimethyl-4,4-bipyridinium chloride) and Glyphosate (n-phosphonomethyl glycine) in Translocation of Metal Ions to Subsurface Soils. Pak J Anal Environ Chem 10:19–24
33. Meride Y, Ayenew B (2016) Drinking water quality assessment and its effects on residents health in Wondo genet campus, Ethiopia. Environ Syst Res 5:1–7. https://doi.org/10.1186/s40068-016-0053-6
34. Mohamed R (2001) Evaluation et cartographie de la vulnérabilité à la pollution de l'aquifère alluvionnaire de la plaine d'El Madher, nord est Algérien selon la méthode DRASTIC. Sci Chang Planetaire Secheresse 12:95–101
35. Moiroux N (2006) Des bassins versants aux écosystèmes aquatiques: développement d'un Système d'Information Géographique sur le bassin du Nariarlé au Burkina Faso. (Master Aménagement du

Territoire et Télédétection). Institut de recherche et de devellopement IRD, Ouagadougou

36. Murat V (2000) Etude comparative des méthodes d'évaluation de la vulnérabilité intrinsèque des aquifères à la pollution: Application aux aquifères granulaires du Piémont LAURENTIEN (Mémoire pour grade de maitres de sciences M.c.). Université du québec, Canada
37. Murat V, Paradis V, Savard M, Nastev M, Bourque E, Hamel A, Lefebvre R, Martel R, Paradis D, Savard MM, Nastev M, Bourque É, Hamel A (2003) R. Lefebvre et R. Martel
38. Nachtergaele F, van Velthuizen H, Verest L, Wiberg D (2012) Harmonized World Soil Databaze - Version 1.2. FAO, IIASA, ISRIC, ISSCAS, JRC
39. Neukum C, Hotzl H, Himmelsbach T (2008) Validation des méthodes de cartographie de la vulnérabilité par investigations de terrain et modélisation numérique. Hydrogeol J 16:641–658
40. NRC (1993) Groundwater Vulnerability Assessment: Contamination potential under conditions of uncertainty. National Academy Press, Washington, DC
41. Ouandaogo/Yameogo S (2008) Ressources en eau souterraine du centre urbain de Ouagadougou au Burkina Faso, qualité et vulnérabilité. Avignon, France
42. Ribeiro L (2000) Desenvolvimento de um i'ndice para avaliar a susceptibilidade dos aqui'feros a'contaminac,a'o,nota interna. *ERSHA-CVRM* 8
43. Saidi S, Bouri S, Dhia HB (2010) Analyse de sensibilité sous SIG de l'évaluation de la vulnérabilité des ressources en eaux de l'aquifère de Mahdia-Ksour Essaf, Tunisie: étude de validité. Rev Sci Hydrol 56:288–304
44. Sarkar S, Das R (2017) PVP capped silver nanocubes assisted removal of glyphosate from water—A photoluminescence study. J Hazard Mater 339:54–62. https://doi.org/10.1016/j.jhazmat.2017.06.014
45. Saxton K, Rawls W, Romberger J, Papendick R (1986) Estimating generalized soil-water characteristics from texture. Soil Sci Soc Am J 50:1–15
46. SOME K, DEMBELE Y, SOME L, MILLOGO J (2008) Agricultural pollution of waters in Nakambe catchements: case of Loumbila and Mogtedo dams in Burkina Faso.Sud Sci. Technol.9
47. Stigter TY, Ribeiro L, Dill AMMC (2006) Evaluation of an intrinsic and a specific vulnerability assessment method in comparison with groundwater salinisation and nitrate contamination levels in two agricultural regions in the south of Portugal. Hydrogeol J 14:79–99. https://doi.org/10.1007/s10040-004-0396-3
48. Tapsoba F, Kere F, Diarra J, Barry A, Lingani H, Dianou D, Dicko M (2016) Etude de l'évolution des éléments précurseurs d'eutrophisation des eaux du Barrage n°3 de Ouagadougou au Burkina Faso. Int J Biol Chim Sci 10:14
49. Tepe Y, Boyd A (2003) Reassement of nitrogen fertilization for sunfish ponds.J Word Aquac Soc**34**
50. Toe A (2007) Utilisation des pesticideschimiques en cultures maraichères et cotonnières dans la region est du burkina faso. campagnes 2005–2006 et 2006–2007. Burkina faso. (rapport d'étude)

51. Tonle I, Temgoua R (2019) Méthodes physico-chimiques usuelles d'analyses des eaux. *Sci. Soc.*, Au coeur de la strategie Scientifique 84–85
52. Ward MH, Jones RR, Brender JD, de Kok TM, Weyer PJ, Nolan BT, Villanueva CM, van Breda SG (2018) Drinking Water Nitrate and Human Health: An Updated Review. Int J Environ Res Public Health 15:1557. https://doi.org/10.3390/ijerph15071557
53. Warrack J, Kang M, von Sperber C (2021) Groundwater phosphorus concentrations: global trends and links with agricultural and oil and gas activities. Environ Res Lett 17:014014. https://doi.org/10.1088/1748-9326/ac31ef
54. Zacharia (2002) Limological overviews.Lakes Reserves Mana.

Figures

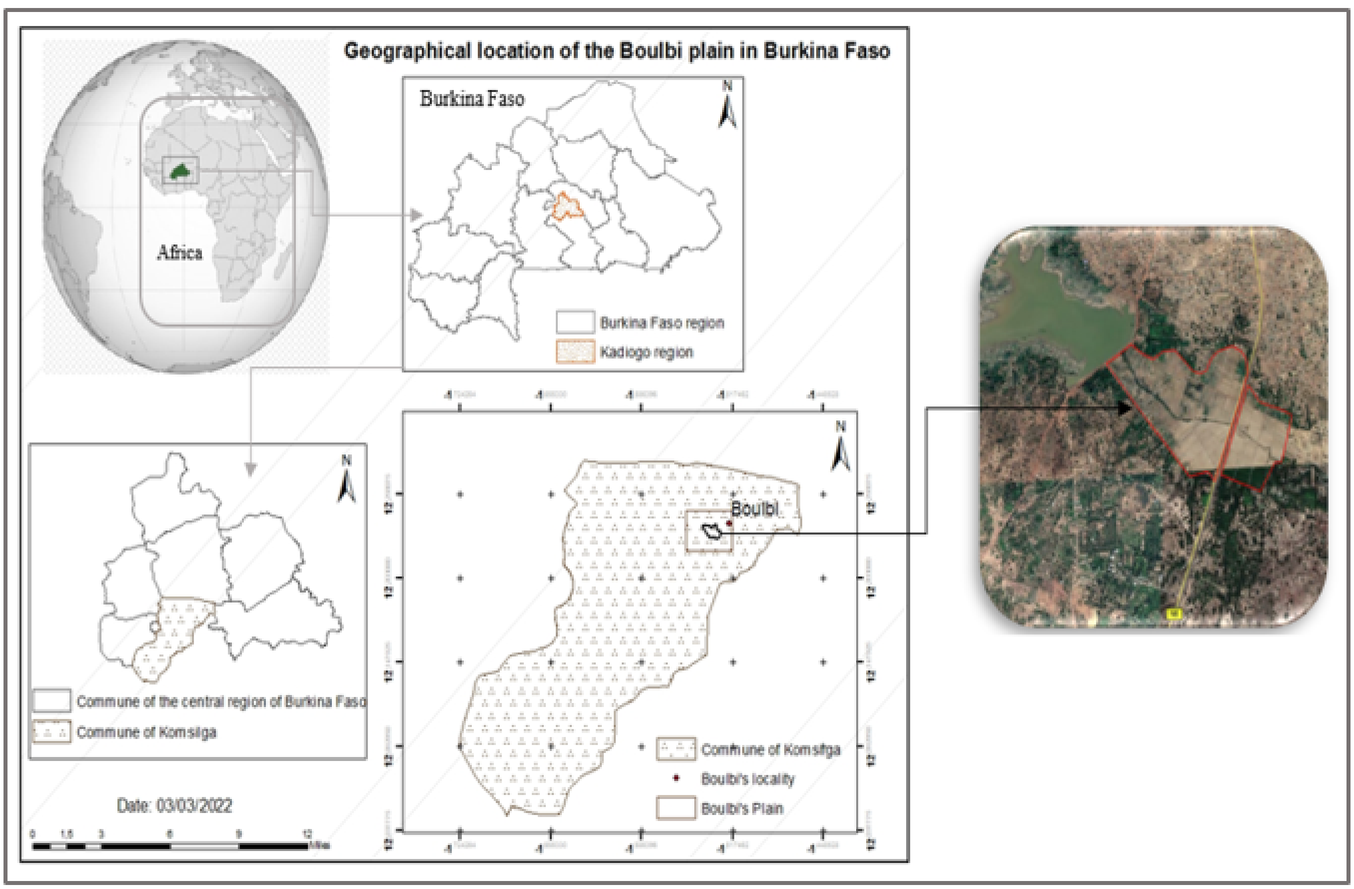

Figure 1

The geographic location of the Boulbi valley bottom

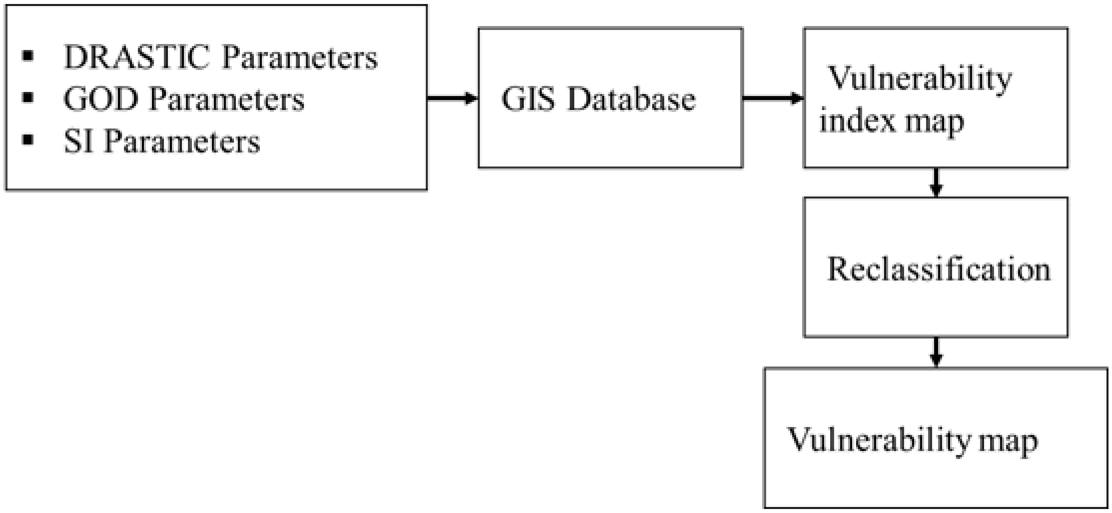

Figure 2

Flowchart for DRASTIC, GOD and SI methods

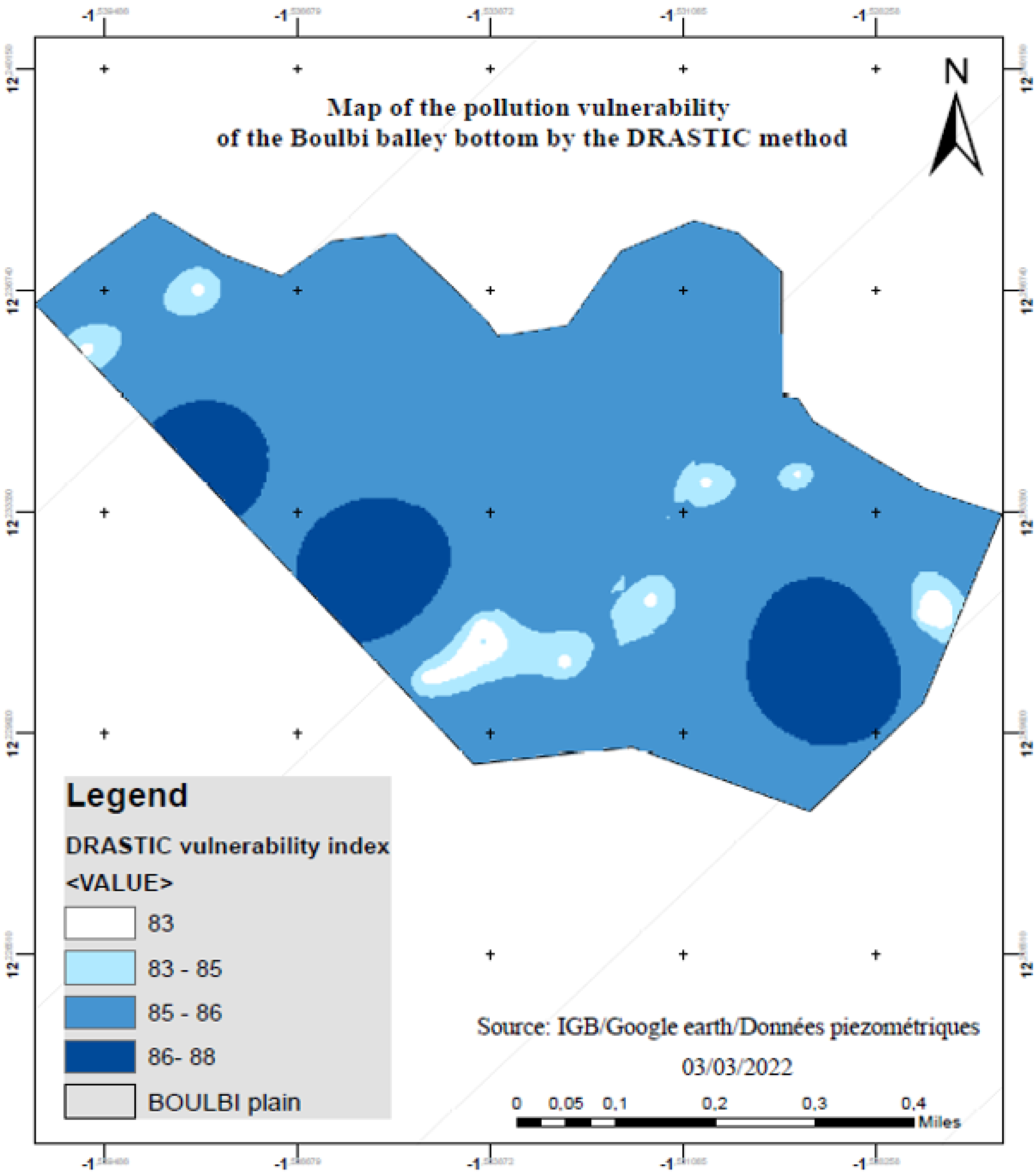

Figure 3

Pollution vulnerability map according to DRASTIC method

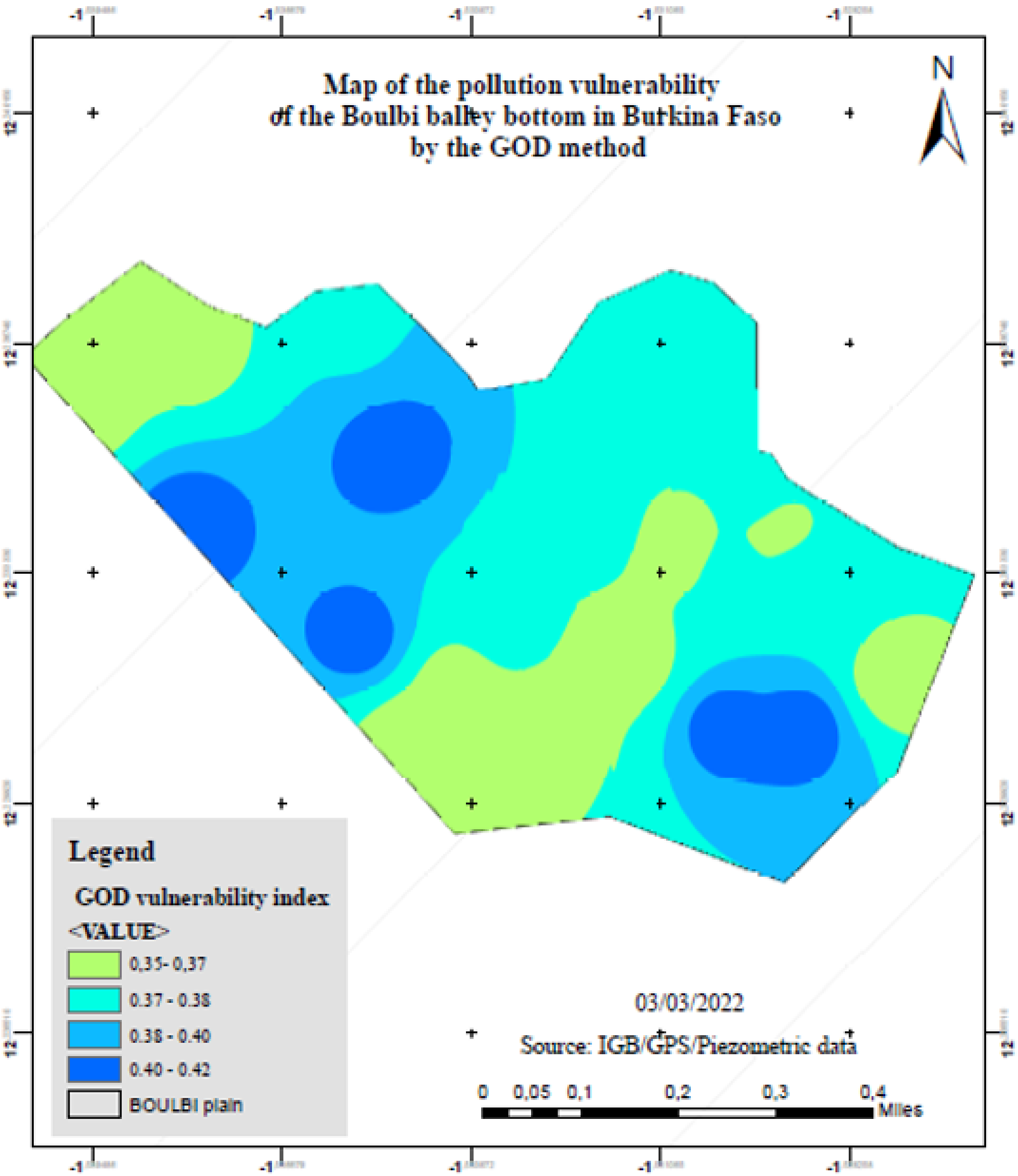

Figure 4

Pollution vulnerability map according to GOD method

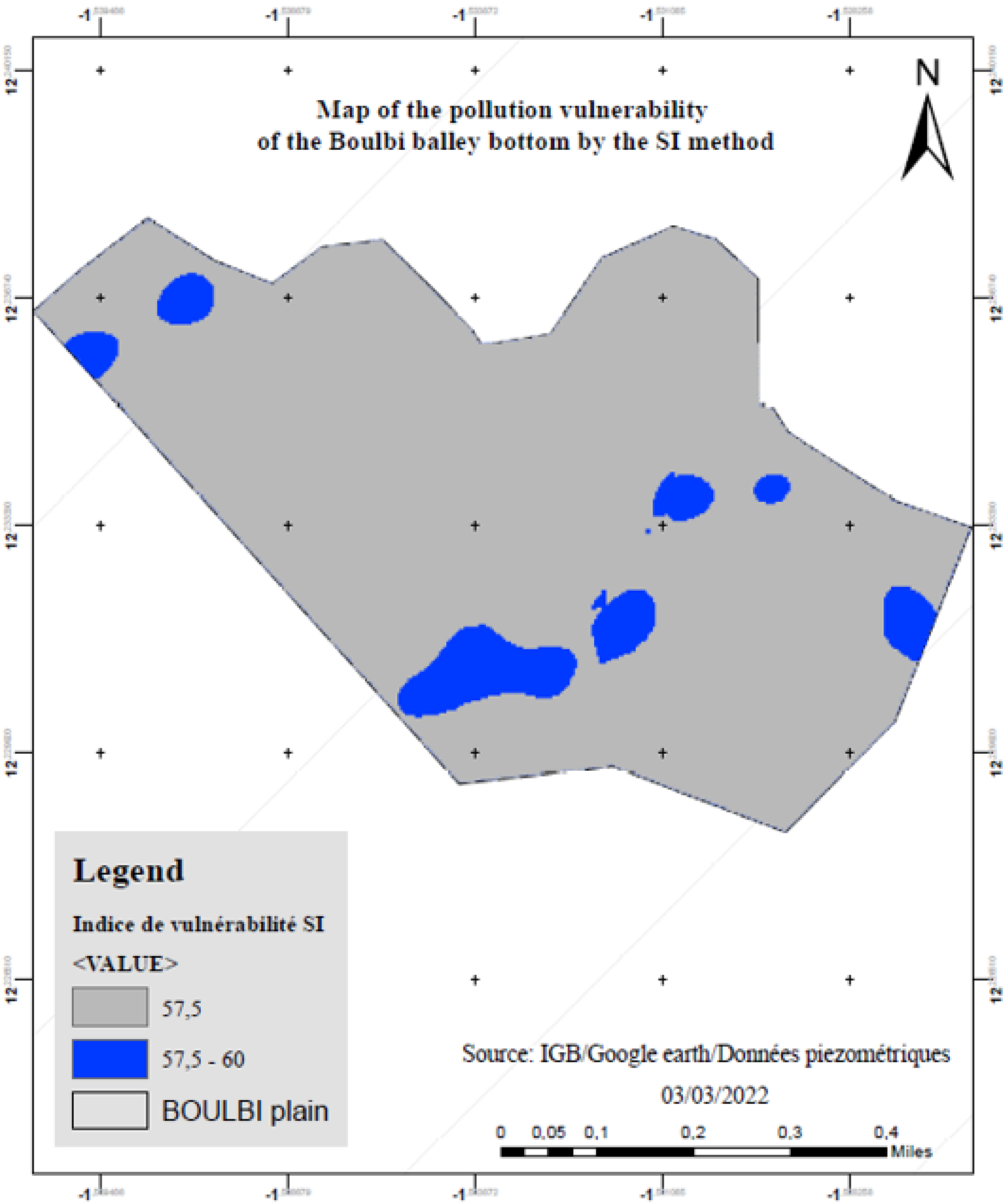

Figure 5

Pollution vulnerability map according to SI method

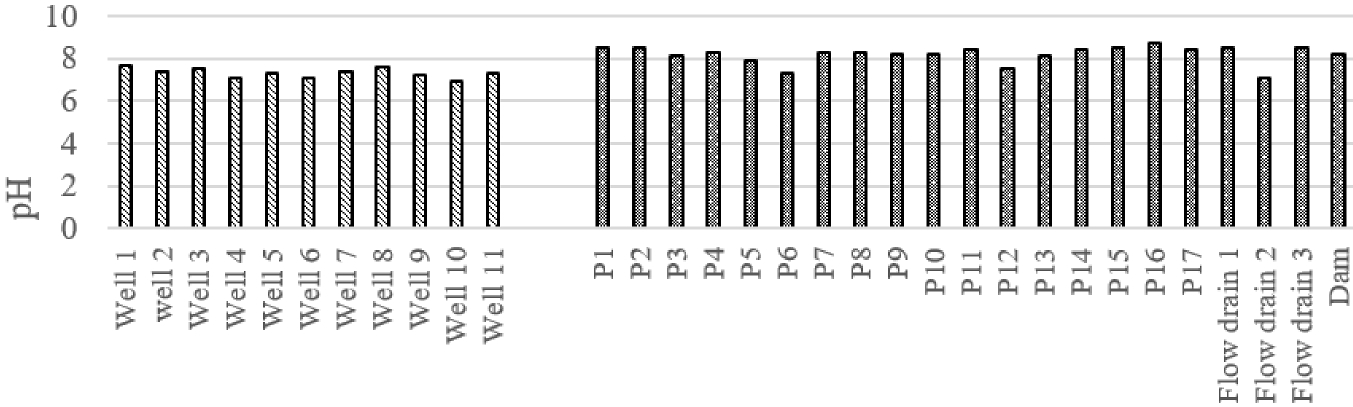

Figure 6

Result of the analysis of the pH in well water and

groundwater from the Boulbi valley bottom in Burkina Faso

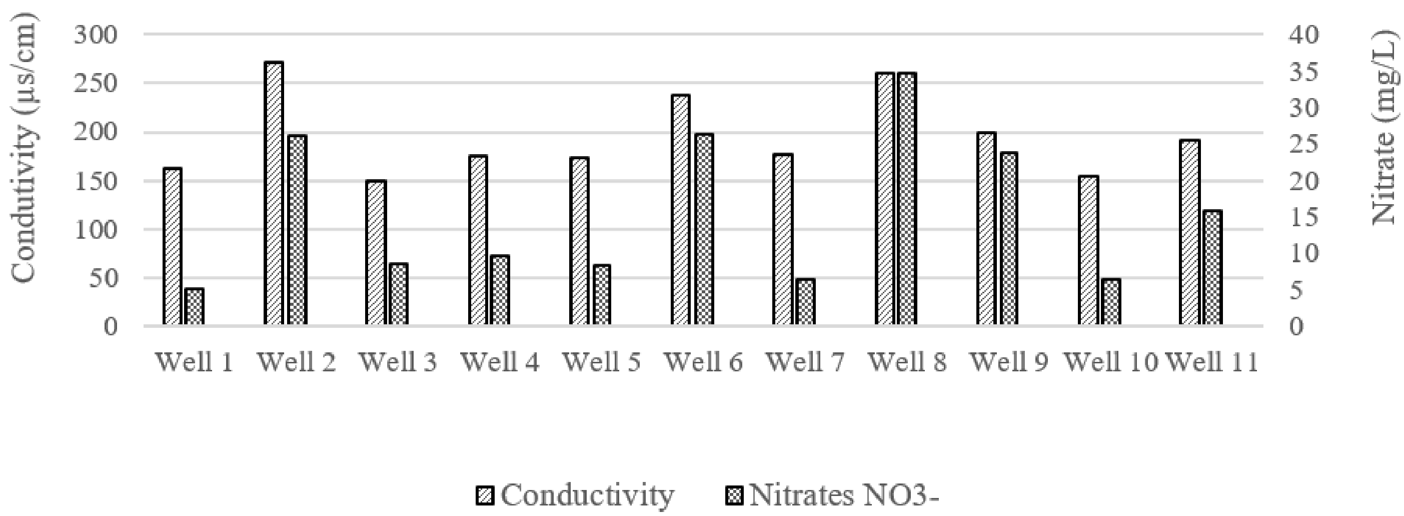

Figure 7

Results of the analysis of the electrical conductivity and nitrate

ion concentration in well water of the Boulbi valley bottom in Burkina Faso

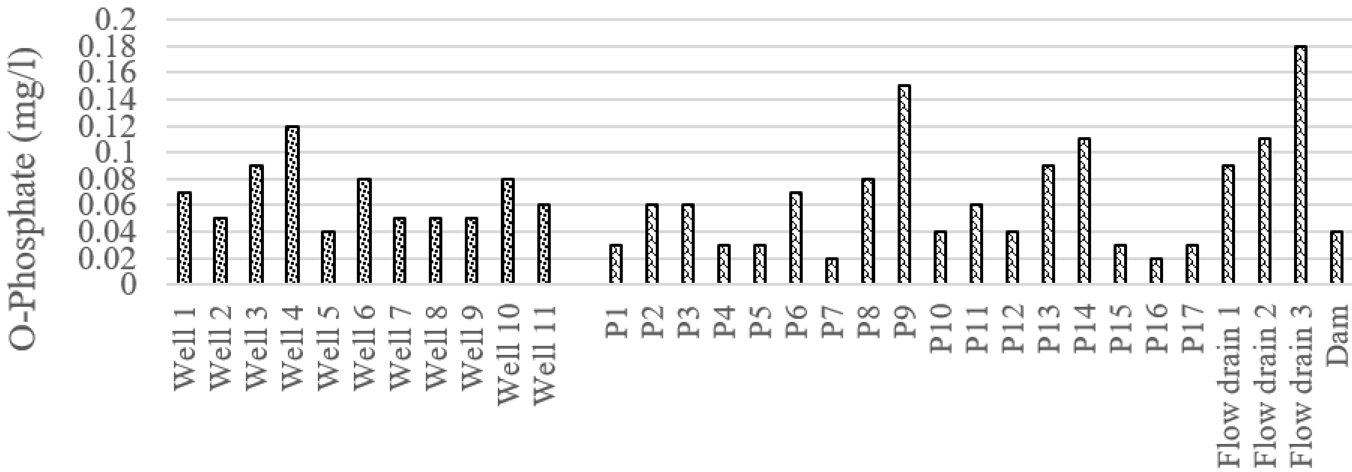

Figure 8

Result of the analysis of the phosphate ion in well water and

groundwater from the Boulbi valley bottom in Burkina Faso

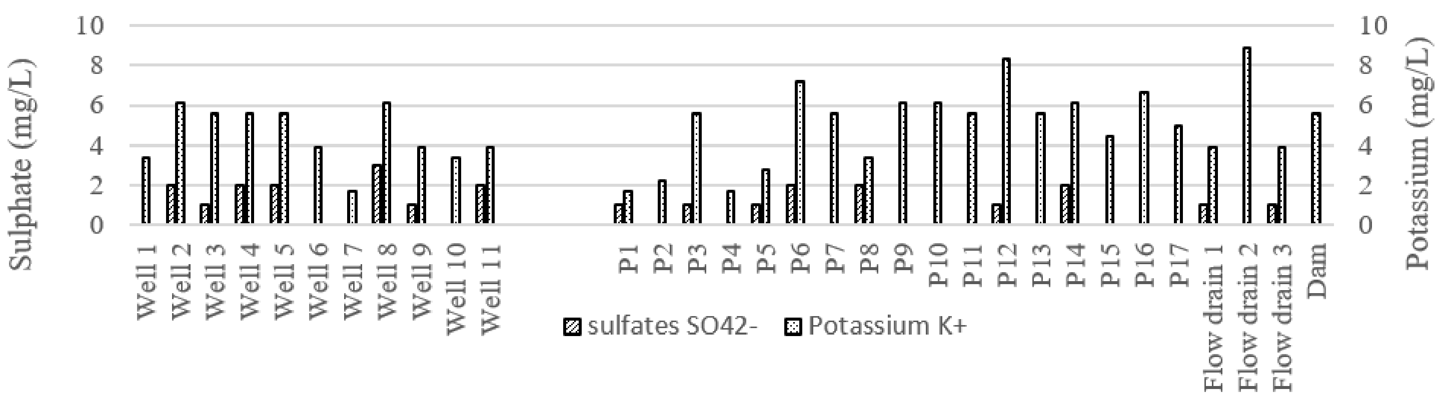

Figure 9

Results of the analysis of the ion sulphate and potassium ion concentration in well water and ground water from the Boulbi valley bottom in Burkina Faso

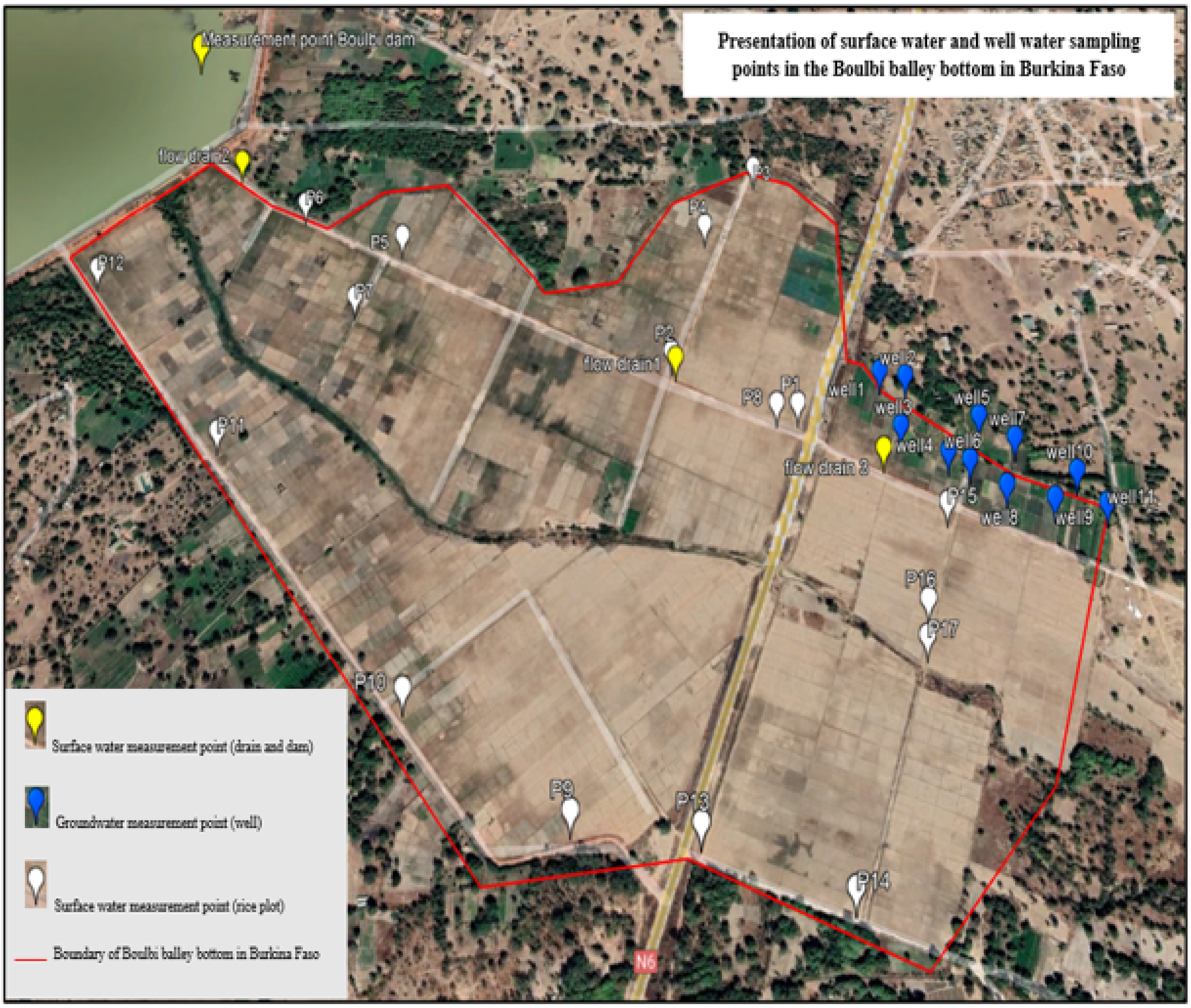

Figure 10

Water withdrawal points on the valley bottom