Hydrological process and origins of the runoff in a granitic basement: the case of the Kolondieba watershed in the south of Mali

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ABSTRACT

The Kolondieba Watershed covering an area of 3050 km\textsuperscript{2} takes place in the southern granitic basement of Mali. It’s used as part of the international program RIPIECSA (Interdisciplinary and Participatory Researches on Interactions between Ecosystems and Climate in Africa) to study the hydrological process occurring in order to determine the origin of the runoff at the outlet. The method used is based on rainfall, hydrometric, piezometric and geochemical monitoring over three hydrological cycles (2009 to 2012). The results show that the runoff starts at the outlet when groundwater rise to high level and stop when it’s lower. Water resource mineralization monitoring based on the electrical conductivity [EC (\mu\text{Scm}^{-1})] and [TDS (mgL\textsuperscript{-1})] showed that the superficial Runoff (Rs) is very close to precipitations with EC=18.54 ± 9.56. The groundwater provided by the wells (shallow aquifers) and the drillings (deep aquifers) are more mineralized than precipitations. Their EC values are respectively: 126.10 ± 95.60 in the wells and 134.40 ± 84.91 in the drillings. The seepages during the drying up is assigned to hypodermic Runoff (Rh) because of their EC = 47.29 ± 22.88 far from the groundwater’s. At the outlet, the EC is nearest the Rs and the Rh ones during the rainy season and the drying up with EC = 42.97 ± 18.89. On the other hand, the mineralisation of the runoff at the outlet comes closer to the shallow aquifer during the baseflow, with a maximum value of 90 \mu\text{Scm}^{-1}. This value is assigned to a depth goes from 2 to 6 meters. So this mineralization is considered like superficial groundwater drainage (Ns) from shallow aquifer because the lithostratigraphic cross drilling showed that the deep aquifers are in 40 meters in average. In these conditions deep aquifers don’t contribute to the runoff at the outlet. Therefore, they are three origins of the runoff in Kolondièba watershed such as: superficial and hypodermic runoff during the wet season and the beginning of dry season plus groundwater drainage from shallow aquifers during the baseflow on the subsurface.

Keywords: hydrological process, watershed, outlet, mineralization, runoff origin

Introduction

West Africa is a vast territory where climate is governed by the movement of the Atlantic monsoon. This part of Africa has been affected in recent decades by more of less severe droughts (Bricquet et al., 1996; Savané et al., 2001; Lebel and Vischel, 2005; Goula et al.,...
2. Data and Methods

2.1. Data
The rainfall data are recorded from 13 rainfall stations distributed over the watershed (see Figure 1) and the height of observations varies from one station to another. The longest column of data belonging to the rainfall station of Kolondieba near the outlet extends over the period 1960-2011. These data were used to assess the impact of climate variability on surface water in the watershed of Kolondieba (Dao et al., 2010). On the experimental period (2009-2012), annual rainfall averages is about 1200 mm on the first two years but in 2011 it was down causing a rainfall deficit of about 33%.

Decadal monitoring to observe the seasonal fluctuations of piezometric level was performed from 36 wells assigned to shallow aquifers. The depth of the wells goes from 10 to 12 m. Deeper water is from 34 drillings made by Helevetas-Mali during emergency program of rural water, consists of granitic cracked in crystalline basement (Figure 2). In addition, 17 surface water points located in lowlands were selected for monitoring the physicochemical parameters (pH, temperature (T°C), Electrical Conductivity (EC) and Total Dissolved Solids (TDS)) measured *in situ* using a multimeter CRISON MM 40.

![Figure 1: Localisation of the Kolondieba watershed and details of the measuring network](image-url)
2.2. Methods

2.2.1. Major ions analytic method details

All major ions: Mg$^2+$, Ca$^{2+}$, Na$^+$, K$^+$, HCO$_3^-$, NO$_3^-$, Cl$^-$ and SO$_4^{2-}$ were analyzed by spectrometry in analytical chemistry laboratory of the University of Bamako. The ionic balance calculated from the formula below.

$$\text{Ionic balance} = \left( \frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} \right) \times 100$$  \hspace{1cm} (1)

Defects resulting balance range from ± 3% and ± 10%. This line meets the standards for chemical analysis (Charlier, 2007).

2.2.2. Methods for determining the origin of the runoff

The methods used are based on the statistical approach on the one hand and on the generalized method EMMA (End Members Mixing Analysis) (Kattan et al., 1987; Probst, 1992; Robson et al., 1990; Christophersen and Neal, 1990; Christophersen et al., 1993; O’Brien and Hendershot, 1993) and improved by Tardy (1993, 1994); Mortatti (1995), Boeglin and Tardy (1997) and Boeglin et al. (1998) other. The statistical method inaccurate is based on an approach that uses a number of analyses of physicochemical data from water compartments targeted. Frequency analysis is a statistical prediction consisting in studying past events, characteristics of a given process (hydrological or other) in order to define the probability of future occurrence. His aim in this study is to calculate the probability of no exceedance of the electrical conductivity in the water compartments targeted. The occurrence of annual variable is estimated by the Hazen method that permits calculating the probability
of non-exceedance $F_A$ of a variable. This probability is obtained by the following formula: 

$$F_A = F(x_i)$$

where $F(x_i)$ is the empirical probability defined by Hazen according to the formula

$$F^*(x_i) = \frac{i - 0.5}{n}$$

with $i$ being the rank of the observation sorted by increasing values, $x_i$ the variable observed, and $n$ the size of the sample.

EMMA method is used to represent a mixture of XY chart (mixing diagram) of chemical signatures identified during sample collection at the outlet by crossing two-two the chemical parameter or hydrodynamic considered good tracer (Alquier et al., 1970; Bazemore et al., 1994, Travi et al., 1994; Ribolzi et al., 1996, Newman et al., 1997).

1. If all possible mixture is represented by a segment then there are two poles (two origins), the hydrochemical extreme values of the segment represent the two poles,

2. If all possible mixture is represented by triangle then there are three poles (three origins), the values of sorting vertices of the triangle represent the chemical signature of the poles,

3. If all possible mixture is represented by a tetrahedron then there are four poles (four origins),

4. Beyond the four poles; we are in a hyper-space and it is difficult to visualize the diagram EMMA (Ribolzi et al., 1996).

3. Results and discussion

3.1. Rainfall

3.1.1. Monthly rainfall

![Figure 3: Monthly rainfall in the watershed](image)
The annual rainfall from 1960 to 2011 has been mentioned in the introduction and in the part one (study area). So, the monthly rainfall rushed over the three years were calculated for the station Kolondiéba and compared to monthly averages prior the first and second break observed in the annual rainfall chronic data. The break came after 1969 in rainfall, led to a decline in the contribution of June, July, August and September. But after 1992, their contribution to normal except that the rainy season that stretched into November now ends a month earlier. The peak rainfall located in August moved in September during 2010 and 2011 (Figure 3).

3.2. Evapotranspiration

Monthly annual potential evapotranspiration (ETP) average from 1981 to 1998 and daily between 2010 and 2011 are different while the extreme values are observed to the same period. From April to May the highest values occur due to low cloud cover while we have the lowest values on the one hand in August because of the peak rainfall and the other in December due to the harmattan (Figure 4). ETP seems to follow the pluviometric variability because it’s very low in 2011 than 2010 due to the pluviometric deficit occurred. Under these conditions, rain is the limiting factor of the evaporation process (Charlier, 2007).

![Figure 4: Monthly Evapotranspiration in the watershed (X-axis represents the monthly variation)](image)

3.3. Runoff

Runoff actually begins in late June and ends in late December under the hydrograph of the monthly averages from 1972 to 2011. This period corresponds to the period of high water at a flow rate Q ≥ 1 m³ s⁻¹. This period is preceded artifacts (small peak flows) from May and followed by the period of low waters which flow Q < 1 m³ s⁻¹, which may gradually decrease until it becomes zero in March. Between March and April, the river dries completely (Figure 5). The hydrograph in 2009 begins in mid-August due to the late in installing materials. Hydrographs of 2009 and 2010 were almost the same size (Qmax = 113 m³ s⁻¹). However, the
2011 hydrograph is very low \((Q_{\text{max}} = 40 \text{ m}^3\text{s}^{-1})\) compared to the first two years. Here, it’s very clear that runoff follow pluviometric variability.

![Figure 5: Annual hydrographs at the outlet](image)

The flow coefficient expressing the ability to produce runoff (Kamagaté, 2006), appears lower for the dry year (2011) that the two wet years (2009, 2010) with a ratio approaching the single to double (Tab.1). Under these conditions, the runoff appears to be dependent on party of stormflow in the watershed of Kolondieba.

**Table 1: Flow coefficient of the watershed based on runoff and rainfall ratio**

<table>
<thead>
<tr>
<th>Year</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall (mm)</td>
<td>1337</td>
<td>1290</td>
<td>1005</td>
</tr>
<tr>
<td>Runoff (mm)</td>
<td>124.1</td>
<td>119.7</td>
<td>49.6</td>
</tr>
<tr>
<td>Ratio (Runoff/Rainfall)</td>
<td>0.09</td>
<td>0.09</td>
<td>0.05</td>
</tr>
</tbody>
</table>

### 3.4. Piezometric

#### 3.4.1. Relationship rainfall - groundwater

Piezometric fluctuations in shallow aquifers follow the seasonal rainfall. Indeed, charging is almost synchronous with the onset of the rainy season from April to May (Figure 6a). The few rainfall located in March, are evaporated as they are directly in contact with a heated floor by the high heat (February-March-April). Daily monitoring of a well located near the gauging station Kolondieba-Tiendaga shows that the first piezometric response to rainfall is about 20 mm of rain (Figure 6b). Charging peaked on average across the basin in September while the drain begins near the end of the rains to reach a maximum between March and April. Piezometric response to recharge is not synchronous in time and space because of delays or anticipations in receiving charging rains exist in the basin due to the rainfall spatiotemporal variability from the upstream to downstream. Over the three years of study (2009-2011), the average discharge of groundwater is from April to September with variable amplitudes. This discharge is related to the low hydraulic conductivity of lateritic clays.
forming the first layers of soil and variable depth of wells. Thus, the annual discharge into the reservoirs of shallow aquifers estimated by the approach of Crosbie et al. (2005) is in the range of 85.5 to 427.5 mm in 2009, from 82.5 to 412.5 mm in 2010 and 74.6 to 373 mm in 2011.

The discharge coefficient $\alpha$ (ratio of annual discharge and rainfall) between 6 and 30% of total rainfall are comparable with values ranging between 4 and 24% obtained by Filippi et al. (1990) and Kamagaté (2006) with this method.

![Figure 6: Relation between rainfall – groundwater in shallow aquifers (2009-2011): a) daily average data of the watershed, b) daily local data near the outlet](image)

3.4.2 Relationship river - groundwater

Various hydrological processes occurring in River-groundwater relationship visible on the watershed are superficial runoff, hypodermic runoff like seepages (temporary superficial groundwater discharge). The intensity of the processes depends on the interannual climate variability. Thus, during the years 2009 and 2010 (wet years), these processes were observed throughout the entire watershed. But, in 2011, dry year, these processes could not be observed. This is probably related to the deficit recorded during charging this year. All of these processes take place mostly visible between October and November. Daily observation of a static level of well located near the basin outlet, is reminiscent of an outflow from the river to groundwater during periods of high water (August-September) and inflow from groundwater to the river during low water (October-February). This experiment shows that the Banifing (main river of the watershed) integrates the conceptual schema of Grimaldi (2004)
on the interactions between surface water and groundwater with a particularity to almost zero in the extreme dry period which goes February to April (Figure 7).

Figure 7: River- local groundwater relationship at the outlet

3.5. Geochemistry

3.5.1. Frequency analysis of physicochemical parameters

Of the three hydrological cycles monitoring (2009-2010-2011-2012), the limit values of physicochemical parameters in different water compartments targeted appear to be reached according to the electrical conductivity (EC), setting integrator all physicochemical parameters. Indeed, the tail distributions of the expressed variable (EC) with a probability of no-exceedance within said compartments have an asymptotic behavior towards the extreme values (minimum and maximum) (Figure 8). The mineralization expressed by the EC for all compartments, is in the range of 4-1300 μS cm⁻¹ on the experimental period. We can notice that lowlands water and seepages are not separable. This is the case with the shallow aquifers and deep aquifers from an EC ≥ 100 μS cm⁻¹. This line of electrical conductivity in Kolondieba is similar to that obtained by Kamagaté (2006) on the Donga catchment in Benin as located in the same Sudanese area despite the area ratio of about 5 times each them respectively.

Figure 8: Limit mineralization of water resources in the watershed (2009-2012)
3.5.2. Physico-chemical characterization of water compartment targeted

Over the three years of monitoring, the rainfall is less mineralized with an EC average of $18.94 \pm 10.47 \, \mu\text{Scm}^{-1}$ followed by lowlands of EC average $= 42.75 \pm 19.50 \, \mu\text{Scm}^{-1}$ very close to seepages ($47.29 \pm 22.88 \, \mu\text{Scm}^{-1}$). The shallow aquifers and deep aquifers stand out with higher average EC respectively $124.1 \pm 83.76 \, \mu\text{Scm}^{-1}$ and $134.4 \pm 84.91 \, \mu\text{Scm}^{-1}$. These groundwaters are very close according to the standard deviation from the average EC. This seems to confirm the semi-conductive aquifers of the study area observed by Mali (1990).

**Table 2**: Average values of physicochemical parameters measured *in situ* in the water compartments targeted (2009 - 2012)

<table>
<thead>
<tr>
<th>Physicochemical Parameters</th>
<th>Precipitations N = 93</th>
<th>Lowlands, N = 760</th>
<th>Seepages, N = 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Min</td>
<td>Moy</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>5.00</td>
<td>6.90</td>
<td>8.43</td>
</tr>
<tr>
<td>T°C</td>
<td>20.30</td>
<td>23.87</td>
<td>27.97</td>
</tr>
<tr>
<td>EC (μScm⁻¹)</td>
<td>3.86</td>
<td>18.94</td>
<td>88.27</td>
</tr>
<tr>
<td>TDS (mg L⁻¹)</td>
<td>2.53</td>
<td>12.79</td>
<td>56.50</td>
</tr>
</tbody>
</table>

The average conductivity observed for all surface water (lowlands) is greater than the observed value ($28.1 \, \mu\text{S cm}^{-1}$) by Tardy *et al.* (2004) on the Niger in Bamako from 1990 to 1992. All waters in the different compartments are of low acidity in the image of an average pH around 6. However, this acidity is relatively higher in groundwater in accordance with the EC. Among them, shallow aquifers appear to be more acidic because of acid chemical elements Si, Al, and Fe, major elements of tropical shallow formations (Orange, 1992).
Rainfall recorded the lowest temperature values followed by lowlands in constant contact with the atmospheric temperature while groundwater is warmer because of the geothermal gradient which increases by 1° C every 30 m depth. The total dissolved solids (TDS) derived from chemical weathering of rocks (Appelo and Postma, 1999) is higher in depth than surface (Table 2). At this end of characterization of different water compartments targeted on the basis of the measured parameters" in situ", it should be noted that their mineralization follows a seasonal variation depending on the interannual rainfall variability. This is very noticeable with water depths including daily mineralization average fell sharply to that of precipitation in the rainy season. In the dry season, it tends to mean monthly values of shallow and deep aquifer little separable because of their probable mix in some places during the season. The mineralization of these peaked at the end of the dry season according of piezometric fluctuations (see Figure 6). The daily monitoring of mineralization in a well near the outlet based on the EC gives very similar to lowlands in rainy season and disconnect in dry (Figure 9).

![Figure 9: Seasonal variability of the mineralization of water compartments: circled points (daily values) and points rimless (monthly values)](image)

**3.5.3. Physico-chemical characterization at the outlet**

The electrical conductivity average at the outlet of 42.97 ± 27.48 μS/cm⁻¹ over the three years is in the same order as the average of lowlands (Tab.3). This average value of EC is slightly more than twice the rainfall and a little over a third of groundwater (shallow and deep aquifers), but very close to seepages (see Tab.2). This applies to the total dissolved solids (TDS) with a mean value oscillating around 27.48 ± 11.80 mgL⁻¹ is similar to values obtained in African rivers: 42, 43, 44 mgL⁻¹ respectively on the Niger at Banankoro, Koulikoro and Ke-Macina; 45 mgL⁻¹ on the Bani at Douna (Picouet et al. 2002); 36.4 mgL⁻¹ of the Congo at Brazzaville (Laraque et al., 1995), 48 mgL⁻¹ on the Ubangi at Bangui (Orange et al., 1995), 42 mgL⁻¹ on the Senegal River at Bakel (Gac, 1986), 44 mgL⁻¹ in the Gambia (Meybeck et al., 1987) and about 33.0 mgL⁻¹ for the upper Niger and its tributaries in Fouta (Orange, 1992; Diallo,1995).
Table 3: Average values of physicochemical parameters measured in situ at the outlet (2009 - 2011) (N=469)

<table>
<thead>
<tr>
<th>Physicochemical parameters</th>
<th>pH</th>
<th>T (°C)</th>
<th>EC (µS cm⁻¹)</th>
<th>TDS (mg L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>5.52</td>
<td>06.62</td>
<td>17.96</td>
<td>12.48</td>
</tr>
<tr>
<td>avr</td>
<td>6.77</td>
<td>24.99</td>
<td>42.97</td>
<td>27.48</td>
</tr>
<tr>
<td>Max</td>
<td>7.99</td>
<td>34.10</td>
<td>92.40</td>
<td>80.40</td>
</tr>
<tr>
<td>0.24</td>
<td>02.32</td>
<td>18.89</td>
<td>11.80</td>
<td></td>
</tr>
</tbody>
</table>

The EC goes from simple to double at the rainy season to dry season like groundwater. In rainy season, the minimum value is comparable to mineralization of rainfall, in the dry one; it is of the adjoining seepages (temporary drain of superficial groundwater during the drying up) with maximum value tending toward the average of shallow aquifer (see Figure 9). The mineralization appears to be flow in these conditions depending on the rainfall and piezometric variability observed highest since the dilution reaches its maximum during the peak rainfall (August-September) and while the maximum mineralization is between March-April, period of subsurface flow at the outlet (Figure 10).

![Figure 10: Seasonal variability of Electrical Conductivity at the outlet according to the runoff discharge (2009-2012)](image)

3.5.4. Determining the origin of runoff at the outlet

Major ions monitored at the outlet does not represent the runoff dynamics as having been analyzed in two sampling sessions, one in dry season and another in wet season. These samples are enough just to get an idea of the maximum and minimum mineralization. It would therefore be impractical to make diagrams EMMA at the outlet from the two sessions in order to get a segment of line because by two points pass a segment, then two origins that does not necessarily represent the reality at the outlet.

In addition, the mixing diagram of the EC and TDS parameters selected as the most suitable tracers for obeying the laws of mass conservation of water and solute is linear according to the linear function that links the two parameters. Under these conditions, we opted for a mixing diagram base on electrical conductivity and runoff discharge (EC-Q) that describes the law of conservation of mass and the solute in this work (see Figure 10). The period chosen is from the exceptional flood (caused by extreme rainfall) to the baseflow (see, Figure 10). During this period, the depletion curve expressed by the law of mallet describes three
types of runoff: superficial runoff, hypodermic runoff and base flow due to groundwater drainage (Barnes, 1939; Roche, 1963; Hewlett and Hibbert, 1967). The results obtained in contrasted hydrological cycles 2010-2011 and 2011-2012 (see, Tab.1), provide a triangular configuration consistent with triple origins identified by EMMA method (Figure 11).

**Figure 11:** EMMA diagram at the outlet based on Runoff and EC mixture during the drying up: Rs = superficial Runoff, Rh = hypodermic Runoff, Ns = Shallow aquifers superficial drainage.

The statistical data obtained by daily monitoring at the outlet show that the extreme values of the parameters measured in floods (higher discharge period) and base flow (lower discharge period) don’t varied enough from 2010 to 2011 (Tab 4, 5). In the flood (Tab.4), Min values of the parameters of mineralization: EC - TDS, respectively 17.79 μScm⁻¹ - 11.39 mgL⁻¹ in 2010 and 22.48 μScm⁻¹ - 12.48 mgL⁻¹ in 2011, show a hydrochemical pole which is part of the margin described by the mean value ± standard deviation of precipitations (see Tab.2). Max values of these two parameters respectively 43.70 μScm⁻¹ - 33.90 mgL⁻¹ in 2010 and 60.14 μScm⁻¹ - 39.28 mgL⁻¹ in 2011 are taken into account by the mean value ± standard deviation.
of seepages (see Tab.2). During baseflow, the Min of mineralization parameters: EC - TDS, respectively 43.60 μS·cm⁻¹ - 27.80 mg·L⁻¹ in 2010 and 48.20 μS·cm⁻¹ - 30.90 mg·L⁻¹ in 2011 show a hydrochemical pole among seepages (see Tab.2). Max values of these two parameters respectively 92.40 μS·cm⁻¹ - 65.40 mg·L⁻¹ in 2010 and 95.30 μS·cm⁻¹ - 68.30 mg·L⁻¹ in 2011 are taken into account by the mean value ± standard deviation of shallow aquifers (see Tab.2). Data for 2009 were not validated because the column is truncated at beginning.

From all conditions understood, the deep aquifers are identified as non-contributory to runoff at the outlet. However, the Min values of EC - TDS closed to the mineralization of lowlands and precipitations (see Tab.2) can be attributed to direct infiltration of superficial runoff to them through the corridors of fractures which are preferentially flows in low-cracked area (Koita et al., 2010) like Kolondieba watershed.

**Table 4:** Average values of physicochemical parameters measured *in situ* in the flood at the outlet (2009 - 2012)

<table>
<thead>
<tr>
<th>Physicochemical parameters</th>
<th>2010, N = 72</th>
<th>2011, N = 91</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Moy</td>
</tr>
<tr>
<td>pH</td>
<td>5.80</td>
<td>6.86</td>
</tr>
<tr>
<td>T°C</td>
<td>24.30</td>
<td>26.71</td>
</tr>
<tr>
<td>EC (μS·cm⁻¹)</td>
<td>17.79</td>
<td>35.48</td>
</tr>
<tr>
<td>TDS (mg L⁻¹)</td>
<td>11.39</td>
<td>22.98</td>
</tr>
</tbody>
</table>

**Table 5:** Average values of physicochemical parameters measured *in situ* during the baseflow at the outlet (2009 - 2012)

<table>
<thead>
<tr>
<th>Physicochemical parameters</th>
<th>2010, N = 133</th>
<th>2011, N = 109</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Moy</td>
</tr>
<tr>
<td>pH</td>
<td>5.64</td>
<td>6.78</td>
</tr>
<tr>
<td>T°C</td>
<td>18.40</td>
<td>23.30</td>
</tr>
<tr>
<td>CE (μS·cm⁻¹)</td>
<td>43.60</td>
<td>73.54</td>
</tr>
<tr>
<td>TDS (mg L⁻¹)</td>
<td>27.80</td>
<td>47.15</td>
</tr>
</tbody>
</table>

Statistical monitoring data confirm the three origins obtained by the EMMA method. So, the superficial Runoff (Rs) is identified by precipitations because of their mineralization is very similar. Hypodermic runoff (Rh) is assigned to the subsurface flow from the drain layers formed temporary after rainfall events and found in the lowlands like rapid Runoff (Rr). According to Tardy et al. (2004), the Rr is a particular reservoir identified only in arid areas, but in humid climate, it is inseparable from the hypodermic Runoff. This Rh (Rr) was clearly identified by Boeglin et al. (1997, 1998) in the Niger River basin in Bamako and by Bustillo (2000) in the Garonne watershed. Watershed Kolondieba (part of Bani, the main tributary of the Niger in Mali) unlike the Niger in Bamako (semi-arid), is under the influence of south-Saharan climate where rainfall is abundant than anywhere else in Mali. This seems difficult to justify the separation between Rr and Rh because of seepages and lowlands mineralization very closed. The descent of water (see Figure 11) characterized by a cessation of rainfalls and the drainage of surface slicks formed temporarily leads to a mixture of Rh and Rs causing progressive mineralization towards the tip of Rh. The top of Rh is reached when all lowlands
are dry. At this moment, the baseflow start on surface and quickly evaporated by the harmattan action (a dry hot wind stemming from the Sahara anticyclone in the direction NE-SW). Soon after, the flow stops at the surface and the relay is then ensured by superficial drainage (Ns) assigned to shallow aquifers because of the maximum mineralization at the outlet of 92.40 µScm\(^{-1}\) and 95.30 µScm\(^{-1}\) respectively in 2010 and 2011 very close to their EC average (see Tab. 2, 4, 5). When another rainy season begins, rising water make the runoff starting quickly from Np to Rs and the process explained start again.

4. Conclusion

The hydrological process study based on hydrodynamic and geochemical monitoring makes understanding the mechanism of the runoff production at the outlet. Indeed, rainfall very few minerals constitute the input signal in the hydrosystem (watershed Kolondieba). At the surface of soil this signal is subdivided like: The first part is the superficial runoff which mineralization is similar to precipitations. A second part seeps into the soil to recharge aquifers and created temporary saturations in the subsurface. This discharge is function of rainfall variability. Thus, the piezometric level of groundwater is higher in wet years and less high in dry ones, this is the case for example of 2011 characterized by a deficit of discharge. The result was the reduction of seepages from 2009 and 2010. The runoff at the outlet begins from June following the decrease of evapotranspiration and superficial runoff increasing on the one hand, and gradual rising of groundwater level on the other. Once the temporary saturation of the soil reaches its maximum during the rainfall peak, infiltration tends to cancel at the expense of runoff on saturated surfaces, this create a temporary equilibrium between river and groundwater. At the end of the rainy season, the balance is broken with the appearance of seepages assigned to hypodermic runoff by their mineralization separate from shallow aquifers and deeper. These seepages come from some places because of the constraints encountered in the soil (soil endured by the armor, slope failure). During dry period, the river evaporates by harmattan effect. This is interpreted as drainage of superficial groundwater because of the mineralization average very closed to the maximum mineralization at the outlet. Deep aquifers do not contribute to runoff at the outlet because of the total drying of the hydrographic network. Once the mechanism of runoff production at the outlet and his origins known, the following work suggests the using of a three parameters mixture model to separate the hygrograph.

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