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Aim and scope

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Contents

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Modeling Consumer Home Composting Intentions for Sustainable Municipal Organic Waste Management in Iran

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ABSTRACT

Home composting (HC) can be a cost-effective strategy for organic solid waste management. This option is also desirable since HC is increasingly automated, with HC machines composting faster than conventional composting in outdoor settings. Besides, HC may reduce organic solid waste management costs, especially for developing countries with scarcer resources. Taking Iran as a study case, the paper examines the influence of variables pertaining to the theory of planned behavior, the value-belief-norm framework, and the technology acceptance model. This study uses data collected from a territory-wide survey (n = 367) of Isfahan's residents to predict HC intentions. The results show that both attitude and subjective norms appear as the most impactful of all variables. These results further vary according to sex, with women being significantly more prone to HC than men. The findings may provide a reference to implement HC in Iran and other developing countries and possibly developed ones.

Keywords: home composting; organic solid waste; pro-environmental behavior; theory of planned behavior; value-belief-norm theory; technology acceptance model

1. INTRODUCTION

The unrelenting increase of organic solid waste is a common problem worldwide [1]. Modern lifestyles and population growth have inevitably increased organic solid waste (OSW) worldwide [2]. To deal with this issue, most developed and developing countries have adopted a hierarchical framework for waste management that involves a descending order of priority: prevention, minimization, reuse, recycling, and disposal [3]. These waste management programs attempt to change consumers' household waste management behaviors to achieve a cleaner environment [4]. Both prevention and reduction strategies have been prioritized for waste management, and thus a significant proportion of studies have focused on these strategies [5–8]. Yet, although waste prevention, minimization, and reuse are the most desirable options in the hierarchy of waste management, their implementation sometimes requires substantial changes in consumers' lifestyles, making them often difficult to implement [9]. Instead, recycling has become one of the most popular waste management options worldwide [10–12]. Besides, recycling is also a critical dimension of socially responsible consumption behavior [13,14], meaning that recycling - more than any other waste management strategy - is crucial to evolve towards more sustainable consumption behavior.

In the literature on household recycling worldwide, most studies have focused on curbside recycling programs and municipal solid waste (MSW) recycling. This is understandable because, in developed countries such as the United States or Canada, for example, the composition by MSW is predominantly composed of non-organic waste such as paper (27%), yard trimmings (14%), plastics (13%), metals (9%), rubber/leather/textiles (9%), wood (6%), glass (4%) and other materials (3%). In comparison, only more than one-tenth (15%) is food (i.e., OSW) [2]. However, there are also some exceptions among developed countries. For example, waste in Spain is almost half (49%) organic, 21% paper, 12% plastic, 8% glass, 4% iron, and 7% other materials [15]. Therefore, the implementation of recycling programs for non-organic waste is of growing interest worldwide [16].

Also, for organic waste, home composting (HC) appeared as an environmental solution at the household level that can reduce waste and turn materials into valuable resources [17,18]. As a form of organic waste recycling activity, HC curbs biodegradable waste volume going into landfill sites such as food and yard waste [19].

In most countries, including the UK [20], Spain [21], Sweden [22], Denmark [23], Japan [24], and Germany [25], home composting is used as a waste management approach. Yet, in developing countries, including Iran, the organic waste volume is comparatively higher [19]. Meanwhile, HC is under-developed. For example, waste production per capita in Isfahan is 500 grams. Of the 1000 tons of daily residual in Isfahan, 650 tons of organic waste can be converted into standard compost fertilizer [26,27]. So, to promote home composting effectively, it is essential to recognize the determinants of HC. However, the existing literature on HC is limited in several aspects.

First, composting is investigated from a managerial standpoint [2]. Second, when taking the individual as the unit of analysis, the literature focuses on the demographic variables leading to HC without exploring the psychological process underlying the behavior [11,28,29]. Third, the exploration of HC from an individual vantage point lacks theoretical foundations for exploring specific intrapsychic variables [20]. Fourth, these studies pertain to HC in developed countries such as Hong Kong and the United Kingdom. At the same time, HC in the context of developing nations is less documented in research. Finally, automated home composting differs from traditional composting due to the need to adopt a new technology to perform HC. Since these kinds of equipment are becoming increasingly popular for HC purposes [30,31], traditional behavioral models may less well apply, and the literature is under-developed in this regard. Albeit not focusing solely on automatic HC, this research fills that void in the literature by modeling the factors that impact home composting. This study thus contributes to the emerging literature about automated composters as well [32].

To fill these knowledge gaps, this paper analyzes first-hand data from a territory-wide sampling survey conducted in 2019. The survey used the stratified random sampling method to sample 367 residents of Isfahan to better understand the determinants of HC intentions in developing countries.

More specifically, this paper used the variables about three seminal theoretical frameworks in consumer choice modeling – the theory of planned behavior, the value-belief-norm theory, and the technology acceptance model – on HC intentions in the context of a developing nation. This study may reference future HC studies and the improved implementation of HC programs in developing and possibly developed countries alike.

2. THEORETICAL FRAMEWORK AND HYPOTHESES DEVELOPMENT

2.1. The theory of planned behavior (TPB)

The theory of planned behavior (TPB) provides a framework for predicting behavior while considering the individual as the unit of analysis. A previous version of that theory known as the theory of reasoned action (TRA) examined the impact of behavioral beliefs and evaluation of behavioral outcomes on attitudes, as well as normative beliefs and motivation to comply with subjective norms, with both attitudes and subjective norms being posited as antecedents to intentions [33]. An attitude is a psychological emotion and indicates a person's negative and positive evaluation of a particular behavior [34]. Subjective norms are the social pressure perceived by the individual to perform the behavior [33]. The first assumption of the TRA is that behavioral intentions lead to behavior, while a series of other factors influence behavior indirectly through intentions [35]. The second assumption of this theory is that behavior is volitional, i.e., voluntarily controlled. Behavior is controlled by a person who behaves differently out of personal choice and not based on external principles or accidents.

Hence, this theory performs well in predicting behaviors done by conscious choice but predicts less well behaviors that are not entirely volitional [36]. Accordingly, Ajzen added the construct of perceived behavioral control to the theory of reasoned action (TRA) and devised TPB [37]. The TPB suggests that behavioral intentions are determined by perceived behavioral control [34]. Perceived behavioral control indicates the extent to which one's behavior is under voluntary control, and perceived behavioral control is defined as one's beliefs about how easy or difficult it is to perform a given behavior [37]. The central argument in TPB is that each behavior is triggered by an intention and the perceived behavioral control. Attitudes and subjective norms are supposed to affect behavioral intentions alone. In sum, attitudes toward behavior, beliefs about the external viewpoints of reference persons, and beliefs about the ability to participate in particular behaviors influence a person’s intention to engage in that specific behavior [38]. However, previous studies on recycling have shown that the three main factors of TPB cannot predict behavior well [19,39]. Given HC's nomological proximity with recycling in that composting is the “recycling of compostable waste” [40], it follows that this theory needs to be complemented with other variables or theories.

According to Fishbein and Ajzen [34], attitude has a positive impact on intentional behavior. Also, Mosler et al. [4] indicate a high correlation between attitude and composting intentions. Most studies suggest that attitude has a significant and positive impact on environmental intentions [4,19,20,39,41–43]. Some studies showed that subjective norms positively correlate with a person’s composting/recycling intention [41,44,45]. Meng et al. [44] indicated a significant positive relationship between social norms and recycling intentions. Besides, Knussen et al. [46] employed the TPB model as a research framework to study recycling behavioral intentions. Their research showed that perceived behavioral control has a significant impact on recycling intention. While supported in the context of recycling, especially in developed countries, we posit investigating those relationships about the TPB in the framework of HC in a developing country. Consequently, we derive the following

hypotheses:

H1: Attitude is positively related to home composting intentions.

H2: Subjective norms positively influence home composting intentions.

H3: Perceived behavioral control has a positive effect on home composting intentions.

2.2. Technology acceptance model (TAM)

One of the most popular and broadly used theories for predicting technology adoption by individuals is the technology of the acceptance model (TAM) [47]. Davis developed this theory in 1989, adapted from the theory of reasoned action [47]. The TAM framework is used to predict the factors affecting adopting new technologies [48]. According to this theory, the adoption of technology is directly related to behavioral intentions. In this theory, perceived ease of use and perceived usefulness affect attitudes, which, in turn, affects behavioral intention [49]. This theory adds a critical perspective to investigating pro-environmental behavior, namely the ease of performing a given behavior and its perceived usefulness. None of the previous theories integrates these crucial variables that are core determinants of behavior. For these reasons, the TAM theory has already been used to predict responsible technology acceptance, such as smart grid technology acceptance [50]. The application of TAM to HC might seem unsettling at this point. However, it should be stressed that HC practices have gradually changed and are increasingly becoming automated. HC systems have progressively moved from being outdoors and manual to indoors and automated with automatic HC units that provide an easier way to get involved with the composting process and maintain it over the long run [30,31]. To control for that technological component, we added the TAM variables.

Therefore, Davies et al.'s [51] technology acceptance model (TAM) involving perceived usefulness and perceived ease of use, as crucial variables of acceptance of technically- or technologically-related practices, seems particularly relevant. It means that individuals first evaluate the cost and benefits of behavior before engaging in it. According to TAM, perceived easiness impacts perceived usefulness, and attitude is influenced by perceived usefulness and perceived easiness. This division of attitude is based on evidence from previous studies that have shown that attitude is not unidimensional [42,51–53] showed that perceived usefulness is positively related to recycling intention. According to extant research, the main research hypotheses about the TAM are as follows:

H4: Perceived ease of use has a positive and significant impact on perceived usefulness.

H5: Perceived usefulness has a positive and significant impact on attitudes towards home composting.

H6: Perceived ease of use has a positive and significant impact on attitudes towards home composting.

2.3. Personal norms

Several studies have examined the relationship between PN and behavioral intention (BI) in proenvironmental and prosocial behaviors. For example, Yuan et al. [54] showed that personal norm has a positive and significant effect on citizens' behavior towards kitchen waste recycling. An empirical study in Taiwan indicated that personal norms have a positive impact on recycling intention. According to Tonglet et al. [1], moral norms and recycling consequences are also important determinants of households' recycling intentions. Accordingly, we posit the following relationships:

H7: Personal norm has a positive and significant effect on home composting intentions.

Many researchers have approved the causal relationship between SN and PN. SN precedes PN because SN reflects the social pressure on a person that guides him/her to decide whether or not a behavior is correct [55–57]. Park and Ha [58] showed that a person's perception of recycling is socially acceptable and will guide his/her decision to feel obliged to recycle. Also, Han et al. [59] identified the prominent role of SN and confirmed the positive causal relationship between SN and PN. Based on these theoretical and empirical works, perceived social pressure on eco-friendly behavior, primarily home composting, would influence a person's moral duty to act pro-environmentally. Therefore, the following hypothesis is presented:

H8: Subjective norms about composting positively affect personal norms related to composting. It should be mentioned that the TPB is capable of integrating new variables. Therefore, this theory can be developed using new variables. Thus, the TPB is central to the research framework, and TAM and personal norms are used to broaden this framework. The integrated research framework is shown in Figure 1.

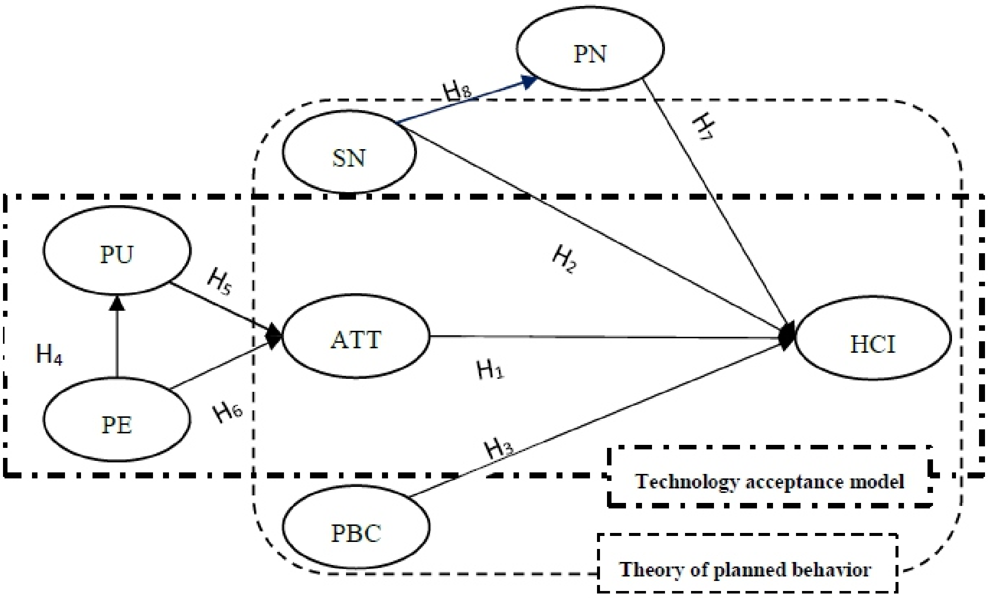

Figure 1. The integrated research framework.

Note: Home composting intentions (HCI); Personal norms (PN), Subjective norms (SN), Perceived behavioral control (PBC), Perceived easiness (PE), Perceived usefulness (PU), and Attitude (ATT).

3. RESEARCH METHOD

3.1. Study area

Isfahan is one of Iran's largest cities, with a population of approximately 2 million people. By population, Isfahan is Iran's third-largest city, and it is also an important city as it is located at the intersection of the north-south and east-west routes that traverse Iran. It has a dry continental climate with four distinct seasons. Isfahan urban waste production per capita is about 500 grams/ per day. In Isfahan, 1,000 tons of daily solid waste is produced by residents, which includes 650 tons of compostable organic waste [26,27].

3.2. Research instrument

The research instrument consists of a questionnaire structured according to the components of the conceptual framework. The five items of PU were adapted from Chen and Tung [42]. Besides, PE was measured by an ad hoc scale of four items developed by the researchers. Also, five PN items were drawn from Tonglet et al. [1] and Liao et al. [60]. The five ATT items were adapted from Liao et al. [60] and

Zeweld et al. [53]. SN was measured using three items by Oztekin et al. [61]. Four items of PBC were adapted from Liao et al. [60]. Finally, eight items of BI were adapted from Taylor and Todd [39]. Also, composting knowledge was measured with a binary question (low or high) adapted from Zhou et al. [62].

The 5-point Likert Scale (strongly disagree = 1 and strongly agree = 5) was used to measure all constructs, except behavioral intention. A five-point Likert scale measured the behavioral intention (from 0 “not at all” to 2 “very high”). Since the questionnaire items were taken from the English research, they were appropriately translated into Persian and then back to English to ensure translation accuracy. A panel of experts confirmed the validity of the questionnaire. A pilot study was conducted to assess the reliability of the questionnaire. The pilot study was conducted in Khomeini Shahr, one of the counties of the Isfahan province. The head of the household was selected to answer the questionnaire. A total of 30 household heads were, therefore, randomly selected to complete the questionnaire. The results showed that Cronbach’s alpha was higher than 0.6. Thus, the reliability of the questionnaire was confirmed [63].

3.3. Participants

The total number of participants in this study amounted to 367 respondents. As shown in Table 1, about 36% of the sample consisted of males, and 64% of the sample consisted of females. This indicated that females show a higher propensity for waste management than men do. This initial finding is in line with previous studies [4,64]. The average age of participants was 45 years old (SD = 7.76).

Means, standard deviations, and correlation coefficients of all variables are presented in Table 2. As can be seen, the correlations were high, especially with HC intentions. Yet, since the correlation coefficients of variables were lower than 0.8, there was no collinearity between the predictor variables [65]. Also, tolerance (TOL) and the variance inflation factor (VIF) were used to detect multicollinearity (see Table 2). The TOL values and VIF values of less than ten and even less than 5, for all variables, indicate no co-linearity between the predictor variables.

Table 1. Demographic characteristics of the sample (n = 367).

Variable	n	Percentage
Gender		
Male	133	36.2
Female	234	63.8
Education level		
Under high school	65	17.7
High school	209	56.9
Technician or Associate	59	16.1
Bachelor & higher	34	9.3
Employment status		
Employed	98	26.7
Housekeeper and/or retiree	269	73.3
Age (average)	(45 years old)	
20–30	11	2.9
31–40	67	18.2
41–50	168	45.7
51<	121	32.9
No. of household members (average)	3.7	

Table 2. Means, standard deviations and correlations.

	M	SD	TOL	VIF	1	2	3	4	5	6	7
1. ATT †	3.34	0.84	0.48	2.08	***0.842***						
2. HCI ††	3.11	0.98			0.775**	***0.839***					
3. PBC ††	3.67	0.74	0.54	1.84	0.604**	0.661**	***0.768***				
4. PE ††	3.15	0.73	0.54	1.86	0.502**	0.671**	0.508**	***0.790***			
5. PN ††	3.17	0.95	0.49	2.03	0.595**	0.693**	0.488**	0.596**	***0.889***		
6.PU ††	3.46	0.55	0.63	1.58	0.582**	0.632**	0.524**	0.444**	0.477**	***0.717***	
7. SN ††	3.04	0.86	0.68	1.47	0.311**	0.451**	0.432**	0.515**	0.430**	0.207*	***0.814***

Note: The diagonal values show the square root of the average variance extracted (AVE). Off-diagonal values represent the unchanged values of the inter-factor correlations. *$P < 0.05$, **$P < 0.01$; † 1 (none) to 5 (high); ††1 (strongly disagree) to 5 (strongly disagree).

3.4. Measurement model

Testing the appropriateness of the model was done in two steps. A confirmatory factor analysis (CFA) using SmartPLS was done to assess overall and local fit and evaluate both reliability and validity. At this stage, four indicators were deleted from the model. The model showed a good local fit. Table S1 shows the local fit with the factor loadings and the results of testing for reliability and validity. As shown in Table S1, the reliability of the scales in the measurement model was confirmed with an alpha coefficient higher than the recommended level of 0.6 [63]. According to Hair et al. [66], the factor loadings of all indicators should be higher than 0.7. Indicators with factor loadings between 0.4–0.7 will be eliminated when they increase the composite reliability and convergent validity. If the composite reliability and validity are higher than their minimum value, indicators between 0.4–0.7 are not omitted [66]. As shown in Table S1, all average variance extracted estimates were over 0.50 [66], indicating convergent validity [67]. Discriminant validity was tested following Fornell and Larcker's criteria [67]. The square root of the average variance extracted for a given construct was compared with the correlations between that construct and all the other variables in the model. As shown in Table 2, the square roots of the AVE of each construct are consistently higher than the corresponding intercorrelations involving those constructs.

3.5. Structural model

After confirming the suitability of the research measurement model, we assessed the structural model. The model showed good overall and local fit indices. The overall fit of the research model was evaluated with the goodness of fit (GoF) index [68]. According to Table S2, the amount of GoF index was 0.468. Therefore, the overall fit of the model was at a suitable level and can be used to test the research hypotheses. Data analysis was performed using SPSS and SmartPLS 2.0 M3 software.

Besides, the predictive relevance of the model is also tested using blindfolding, as shown in Table S2. HCI, attitudes, PN, and PU were used as target constructs. Q-square values greater than 0 indicate the predictive validity of the model construct. The Q-square value for HCI was 0.713, which shows the predictive relevance for HCI. The same applies to attitudes (0.406), PU (0.250), and personal norms (0.788). We also estimated the R-square values to identify further the effect of hidden exogenous variables on the endogenous variables and represented the predictive power of the model. As shown in Table S2, HCI displayed the highest R-square (0.727), followed by personal norms (0.185), PU (0.198), and attitudes (0.413), thus indicating that the model explains from one third to two-thirds of these variables. Overall, this is a good result in the social sciences context, where these values are typically low. The amount of R-square, F-square, and Q-square indicate model quality.

4. RESULT

The results are presented in two stages. First, descriptive and inferential statistical analyses were used to examine if any significant difference exists among home composting intentions and other integrated model variables concerning gender. Second, research hypotheses were tested based on the integrated model.

4.1. Results of descriptive and inferential statistics' analysis

A series of independent t-tests were used to detect any difference in the mean of variables. Based on Table 3, it appears that females score significantly higher than men on every dimension, especially on HC intentions. These results support extant studies that emphasize that women are more prone to pro-environmental behavior and reflected in latent psychological constructs [4,64].

Table 3. Independent t-tests.

Variable	Gender	M	SD	*t-value*
HCI	Male	2.605	0.824	8.080***
	Female	3.402	0.952	
ATT	Male	3.068	0.861	4.754***
	Female	3.500	0.794	
PN	Male	2.833	0.948	5.297***
	Female	3.368	0.894	
PBC	Male	3.400	0.737	5.362***
	Female	3.821	0.694	
PE	Male	2.882	0.696	5.590***
	Female	3.308	0.712	
PU	Male	3.336	0.598	3.383***
	Female	3.534	0.502	
SN	Male	2.764	0.904	4.751***
	Female	3.193	0.788	

***Sig. < 0.001

The results also showed that an independent yard in the house indicates higher intentions of home composting (t = 10.64, Sig. = 0.001). A household without a separate yard could not recognize the composting benefits. This is confirmed by Loan et al. [19] and Oztekin et al. [61].

4.2. Hypotheses testing

Table 4 presents the results of the structural model testing. The results indicate that attitudes significantly impact HCI ($\beta = 0.451$, Sig.< 0.001). Subjective norms have a considerable effect on HCI ($\beta = 0.220$, Sig. < 0.001). PBC has a significant relationship with HCI ($\beta = 0.209$, Sig. <0.001).

Personal norms are positively related to HCI ($\beta = 0.278$, Sig. <0.001). Also, perceived usefulness has a significant impact on attitude ($\beta = 0.447$, Sig. <0.001). Further, subjective norms positively relate to personal norms (β = 0.430, Sig. < 0.001). Finally, perceived easiness has a significant influence on both perceived usefulness (β = 0.444, Sig. < 0.001) and attitudes (β = 0.502, Sig. < 0.001). Collectively, the results provide evidence of support for H1-8. Table 4 provides the beta coefficients and p-values for each hypothesis. Figure 2 illustrates the R-square values and beta coefficients for the model.

Table 4. Hypotheses testing.

No.	Hypothesis	*β*	s.e.	*t*	Sig.
H1	ATT →HCI	0.4515	0.0774	5.8323	< 0.001
H2	SN → HCI	0.2209	0.0402	5.4881	< 0.001
H3	PBC → HCI	0.2091	0.0641	3.2629	< 0.001
H4	PE → PU	0.4449	0.0449	9.9163	< 0.001
H5	PU → ATT	0.4479	0.0571	7.8493	< 0.001
H6	PE → ATT	0.5027	0.0511	9.8299	< 0.001
H7	PN → HCI	0.2785	0.0569	4.8987	< 0.001
H8	SN → PN	0.4307	0.0499	8.6284	< 0.001

Note: *β* = beta coefficient; s.e. = standard error; *t* = t-value; Sig. = level of significance.

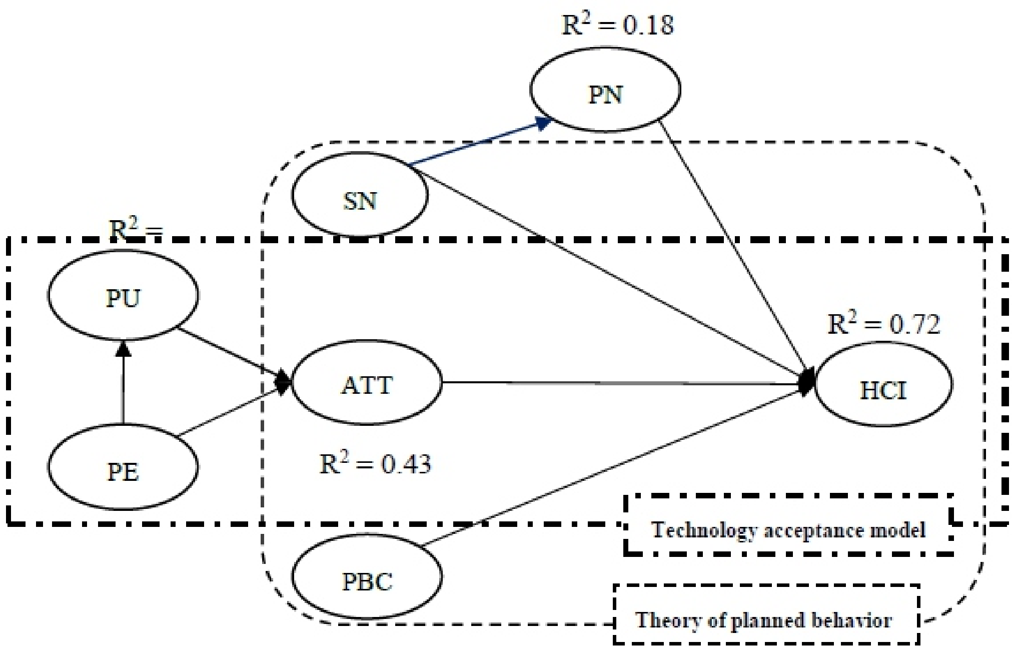

Figure 2. The conceptual model with the estimated results.

5. DISCUSSION OF THE RESULTS

H1, suggesting that attitude has a positive and significant effect on behavioral intentions, was confirmed. So, people with a positive attitude toward home composting are more likely to engage in that behavior. This was consistent with the results of Chen and Tung [42], Edgerton et al. [20], Loan et al. [19] as well as Taylor and Todd [39]. More specifically, individuals who consider home composting as a good, hygienic, and rewarding practice were more prone to engage in HC.

Also, based on the findings, subjective norms are positively and significantly related to behavioral intentions. This was not consistent with Taylor and Todd [39] but was consistent with more recent findings such as those of Chen and Tung [42], Oztekin et al. [61], and Liao et al. [60]. Increasing public interest in environmental issues and positive sentiment in this regard in public opinion worldwide might account for the more recent level of significance of subjective norms on behavioral intentions [69].

The third hypothesis was about the positive impact of perceived behavioral control on behavioral intention. This hypothesis was confirmed by the findings, consistent with past research [1,39,60,61]. This result indicates that having the ability to perform HC in terms of sufficient skills, space, and time can positively affect behavioral intention.

The seventh hypothesis related to the positive influence of personal norms on behavioral intentions. The results confirmed this hypothesis and were consistent with Chen and Tung [42] and Tonglet et al. [1]. According to research findings, a person who adheres to specific environmental protection principles has higher intentions to perform HC.

One of the reasons that can lead to individuals' indifference about the environment in general, and HC, in particular, is the ignorance of the consequences related to the performing of a specific behavior [70]. Awareness of the positive consequences or perceived usefulness of HC makes one think about this behavior and potentially develop a positive idea [51]. The results demonstrated support for the hypothesis that awareness of the beneficial consequences of compost is positively related to attitudes towards HC. The link between awareness of consequences and attitudes is in line with Bamberg and M er [52], Chen and Tung [42], as well as Zeweld et al. [53].

Finally, if HC is perceived as being easier to perform, this will positively impact attitudes the most and, to a lesser extent, awareness of the consequences. This result matches Taylor and Todd's [39] and Zeweld et al.'s [53]. It can be argued that people who think HC is not complicated and challenging will, first of all, develop a more positive attitude about that practice, and secondly, be more aware of their responsibility to engage in HC. It is also interesting to observe that perceived easiness impacts attitudes much more strongly than awareness of consequences.

6. CONCLUSION AND IMPLICATIONS

6.1. Theoretical implications

This research aims to develop and estimate a model that examines the impact of various cognitive factors on household composting intentions in a developing nation. An integrated model combining the theoretical foundations of the theory of planned behavior and the technology acceptance model was used to determine the factors affecting home composting in the context of a developing country, namely Iran. This is the first study to combine these theories in an original integrated framework to improve the level of predictability of HC intentions. Consequently, no less than two-thirds (72.7%) of the overall variance in HC intentions was explained by the model, a remarkable performance for a study in the context of the social sciences. Besides, the study offers several interesting theoretical contributions to research.

First, most of the past research focused on recycling and in the context of developed and sometimes developing nations [10–12]. However, this study shows that several hypothesized relationships overlap significantly with those investigated in the extant literature about recycling or other pro-environmental behaviors [1,52,59,60]. Although these results will need to be replicated in other developing countries using home composting intentions or even behavior as the focal point, they are encouraging. In fact, in line with the spillover theory positing inter-resemblances between proenvironmental behaviors [40], this would mean that results about recycling or PEB in other contexts might potentially apply to HC and in developing contexts as well.

Second, and more specifically, the primary assumption in this study was the centrality of behavioral intentions. There is no behavior unless there is a behavioral intention [34,37]. According to the integrated model study results, HC intentions were directly influenced by the following cognitive factors: personal norms, subjective norms, perceived behavioral control, and attitudes. Besides, the integrated model results showed that perceived usefulness and perceived easiness indirectly lead to home composting intentions.

Thus, the results suggest that holding strong personal principles constitutes one of the most critical determinants of HC intentions in a developing country context. In line with the VBN theory [70], these personal norms are formed by social norms (i.e., subjective norm), which increase the holding of these norms.

According to the integrated model, behavioral intentions were influenced by subjective norms. Yet, since we did not differ between injunctive and descriptive norms [71], we do not know which type of norm has the most substantial effect. Findings further showed that perceived behavioral control had a positive and significant effect on behavioral intention. These results are in line with the traditional TPB. Finally, attitudes exerted the least strong impact on intentions. These results are not surprising since past findings showed that attitudes have the lowest predictive capability consistently in pro-environmental intentions [71,72].

Finally, in line with the TAM model, perceived easiness constitutes a very important contributor to positive attitudes toward HC composting. This finding underscores the appropriateness of investigating HC with a technology-oriented model given the sharp increase in indoor and automated HC systems [30,31].

6.2. Managerial implications

The results of the present study have important implications for managers and policymakers. First, based on the results, females tend to be more willing to perform home composting than males. This is not surprising since women are more often involved in composting initiatives in developing countries, whether through economic empowerment or community programs involving composting or through their higher commitment to household management [73–75]. Therefore, home composting programs and training should prioritize females.

According to the results, men scored significantly lower than women on every dimension under study, including the primary independent variable of social norms and the dependent variable of HC intentions. Yet, this result is not specific to a developing country such as Iran. A large body of research has shown evidence of a small but consistent “gender gap” in environmental views and opinions.

Females are more concerned about the environment than males and have stronger pro-environmental opinions and beliefs [76]. Altogether, these results suggest that fact-based public education initiatives about the environment and HC should be targeted towards males. However, past research suggests that females will be more open to such initiatives [77], and thus, the impact might be higher among females.

We recommend involving males too or using another fact-based approach towards males to increase the overall level of awareness.

Since HC is a new sustainable strategy in developing countries, enhancing the attitude, personal norm, subjective norm, and perceived ease can increase the number of individuals that are eager to home compost.

Accordingly, it can be concluded that policy-makers and business developer should focus their efforts on three aspects: 1) improving communication about environmental issues related to untreated organic waste; 2) raising people's awareness and familiarizing them with the positive consequences of composting and the stages of compost production, and 3) instilling a sense of responsibility for HC to reach the positive benefits related to HC. Altogether, these measures should contribute to enhancing the positioning of HC as an important personal norm.

After personal norms, subjective norms were identified as the second most impactful variable on HC intentions. Accordingly, it can be concluded that it is essential to use pyramidal networks of influence. This means identifying key influencers in the community to forward the message about the importance of HC via word-of-mouth to their followers.

The findings demonstrated that perceived behavioral control had a positive and significant effect on behavioral intention. Therefore, it is suggested to strengthen individuals' perceptions of the ability to perform HC through educational and promotional brochures at the city level. Practical indications about the amount of time or resources needed to perform HC are highly recommendable in this regard.

It should be noted that the attitude toward compost was the most crucial direct predictor of behavioral intention. Therefore, local media can encourage a positive attitude among citizens by increasing awareness of this sustainable strategy through advertising, entertainment, or informational programs.

7. Limitations and directions for future research

We developed an integrated model for predicting HC intentions in developing countries. Although the results were very conclusive since all the hypotheses were supported, we did not compare to what extent this process might differ between a developed context and a developing one. Future research might consider using multi-group structural equation modeling to assess potential differences. Besides, we did not distinguish between injunctive and descriptive norms despite the recent call to do so [71]. Consequently, future research might consider distinguishing between these two constructs. Conflict of interest The authors unanimously declare that this paper is free from any conflict of interest.

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Antibiotic Resistance from, and to the Environment

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ABSTRACT

Antibiotic resistance currently causes hundreds of thousands of deaths worldwide; it is a major and growing public health threat globally. The origins of many resistance genes in pathogenic bacteria can be traced down to the environment; while a staggering number of resistant bacteria and resistance genes, selected for by human activities, are released into the environment. The nature, quantities and fates of this bidirectional flux of organisms and genes are mostly unknown. In order to understand the evolution of resistance within clinical settings, and the impact of the release of resistant bacteria into the environment, it is crucial to assess these questions and to assemble an integrated view of the problem. This review aims at providing an update on related issues previously discussed elsewhere, and to contribute to the comprehensive understanding of the environment as a source, receptacle and reservoir of antibiotic resistance.

Keywords: antibiotic resistance; wastewater; soil bacteria; antibiotic usage; horizontal gene transfer

1. INTRODUCTION

Bacterial resistance to antibiotics was, before the advent of COVID-19, one of the most pressing public health issues worldwide. Even during the first year of COVID-19, the recognized death toll worldwide (about 1,800,000, according to the Oxford Martin School, ourworldindata.org) was "merely" 2.5-fold the estimated number of deaths that, year by year, have been attributed to antibiotic resistance (approximately 700,000, according to O'Neil [1]). Moreover, while it is likely that the mortality of COVID-19 would eventually diminish, after the application of vaccines already available, antibiotic resistance is predicted to keep growing, and to claim the lives of 10 million people each year, by 2050 [1]. Three years after the publication of the report containing the figures above, and of a high level meeting of the United Nations General Assembly [2], no significant advance was achieved to try and harness the increasing trend of antibiotic resistance [3].

For many people, being a health crisis means that antibiotic resistance is only to be found in the clinical setting; for others, although aware of the presence of resistance in the environment, this is not more than a biological curiosity, with little clinical repercussion. Of course, in the short term and for the infected patient, it is much more of a threat to find an antibiotic resistance phenotype in a bacterial pathogen than it would be to detect a resistance gene in an innocuous, environmental microorganism. However, these harmless bacteria are acting as reservoirs and "incubators" of sorts, that collect, mix and release resistance determinants along with mobility and perhaps even virulence genes which, sooner or later, make their way back to human populations. To have an accurate idea of the presence and extent of antibiotic resistance in the environment serves at least two main purposes: (a) to measure the resistance that is being selected by, and released into the environment by humanrelated activities, ranging from clinical and agricultural usage, to wastewater treatment and nonantibiotic biocides; and (b) to timely detect resistance determinants that are yet to cause clinical problems, but that are likely to arrive to the clinical setting, reducing the efficacy of our already limited antimicrobial arsenal. Many of the issues analyzed below have been previously reviewed (e.g., [4]); this paper will update aspects pertaining to antibiotic resistance in the environment.

There are two different ways to address the issue of antibiotic resistance in the environment. On the one hand, it is possible to analyze the presence of antibiotic resistant bacteria (ARB) and antibiotic resistance genes (ARG) in the environment, much before antibiotics were discovered by humans and released massively into the environment. Under this scope, the public health crisis posed by antibiotic resistance might very well be the consequence of clinically-relevant bacteria acquiring such ancient resistance determinants, under the selective pressure of human-made antibiotics. On the other hand, the release of ARB and ARG into the environment, that have been selected for by the clinical and agricultural use of antibiotics, can be seen as a form of anthropogenic environmental pollution. To think of the release of organisms, or even genes, as "environmental pollution", might sound exaggerated or paradoxical; but ARB/ARG are just that. While not "human-made" in the sense of actual manufacture, as are chemical pollutants, or noise and light; ARB/ARG have been vigorously selected by the reckless abuse of antibiotics, and are being released in massive amounts.

As both scopes are true, it is necessary to address them simultaneously, and to understand their interactions and intricacies to have a full picture of the nature and impact of the presence of resistance in the environment. This is a dynamic, bidirectional process, that varies widely from one location to another, because of the differences in antibiotic usage, wastewater management, and the presence of non-antibiotic selective pressures, among many other things. Most examples and study cases come from developed countries, although it is likely the non-developed countries the ones that contribute the most to this problem. Hence, while there is plenty of information available, surely there are many "unknown unknowns" (Donald Rumsfeld dictum) on this subject.

2. WHAT IS "RESISTANCE"?

Before actually addressing the presence of ARB/ARG in the environment, it would be necessary to define "resistance". The first relevant issue around resistance is to distinguish intrinsic resistance from acquired resistance: the former can be considered as an inherent ability of certain bacterial species to withstand the effect of certain antibiotics (e.g., anaerobic bacteria are intrinsically resistant to aminoglycoside antibiotics, because those drugs require the presence of an active respiratory chain to get into the bacterial cell; enterococci are intrinsically resistant to cephalosporins, because they lack the particular kind of penicillin-binding proteins to which cephalosporins bind). Acquired resistance, on the other hand, is a trait that is not inherent to the species, but was gained, either by mutation or horizontal gene transfer. As intrinsic resistance defines the spectrum of each antibiotic, it has always been a limitation of such antibiotic; acquired resistance is the one that poses a serious public health threat.

Being essentially a clinical problem —resistance hinders the ability of antibiotic treatments to cure infections, it is defined in clinical terms. Hence, an organism is deemed "resistant" if such acquired trait results in the increase in the minimal inhibitory concentration (MIC) of an antibiotic, high enough to cause the therapeutic failure of such antibiotic if it is used to treat an infection caused by the organism. This simple definition introduces a first problem, as the concentration of an antibiotic varies from one site in the body to another, making then possible, for instance, to treat an infection caused by the same germ in the urinary tract, because the antibiotic reaches high urinary concentrations; but not on the skin, because the same antibiotic fails to reach inhibitory concentrations in such tissue. Therefore, under the previous definition, the same germ is "susceptible" if it causes a urinary infection, but "resistant" if it causes a skin infection. Nevertheless, there are recognized "breakpoints", i.e., MIC values below which an organism is deemed "susceptible", and above which it is deemed "resistant". This oversimplification allows for the epidemiological studies to calculate rates of resistance, regardless of the body site each organism is isolated from. (There is a remaining issue about who and how those "breakpoints" are established; there are several organizations tasked with this, in different countries or regions, such as the CLSI in the US, and EUCAST in the EU. Due to slight variations, the same organism can be "susceptible" to an antibiotic in the US, and "resistant" in Europe, or vice versa.) As a natural consequence, an ARG is the one that encodes the resistance phenotype as described above. Clear cut examples could be the genes encoding beta-lactamases, which can cause a hundred- or thousand-fold increase in the MIC of beta-lactam antibiotics. There are, however, some cases where this definition is not clearly followed; for instance, qnr genes, that are plasmid-borne genes mediating "resistance" to quinolone antibiotics, can cause an increase in the ciprofloxacin MIC, from 0.06 μg/mL to 0.5 μg/mL, but still below the typical breakpoint for resistance, which is 4 μg/mL. While the role of qnr genes in clinical failure, as well as in the gradual increase to full-resistance, is well documented, genes such as these are more in a "grey zone" in terms of definition.

This issue gets much more complicated when ascertaining resistance in the environment. As many environmental bacteria are mostly innocuous, what antibiotics should be tested, to begin with?

The ability to withstand clinically-achievable concentrations of antibiotics seems irrelevant for nonpathogenic bacteria. The line between intrinsic and acquired resistance is also blurred, as the susceptibility of environmental bacteria to antibiotics has only recently being explored in numbers large enough to distinguish between either kind of resistance. All these issues pose technical problems when trying to assess the existence of resistance in the environment, both the one predating the human use of antibiotics, and the one caused by it. To decide which antibiotics to test, and what MIC breakpoints are relevant, is still a matter of discussion. With metagenomic assessments getting in vogue, the definition of ARG is crucial, as databases currently used list many non-transmissible, "housekeeping" genes, that when mutated or overexpressed lead to a resistance phenotype, but pose little to no danger in clinical terms. These "resistance" genes, very much akin to intrinsic resistance, are causing serious misinterpretations of metagenomic data of all sorts. There is a pressing need for these kinds of studies to evolve beyond the mere detection of "resistance" genes with the sole purpose of publishing a paper. Again, all of these have been previously reviewed and discussed [4]; however, it is important to remind the reader of a relevant paper on the issue [5].

3. RESISTANCE IN THE ENVIRONMENT

It is important to set aside two main categories of ARG/ARB that have been found in the environment: (a) those that predate the discovery and usage of antibiotics by humans, which could be taken literally as detected before the 1940's, but that most often refers to those that have existed for thousands or millions of years; and (b) those that have been selected in human-made environments (i.e., clinical and agricultural settings) and then released into the environment, to be detected in soils, water bodies and wildlife. As will be discussed below, the former have been, and continue to be the source of many ARG of clinical relevance, once they get out of their ancient reservoir and into pathogenic bacteria; while the latter can serve as indicators of the wide reach of this kind of "biological pollution" and of undetected or unknown selective pressures that keep or even enriches their presence in supposedly antibiotic-free environments. The release of "human made" ARG/ARB into the environment is also a major cause of concern, as these organisms often also carry determinants that confer resistance to non-antibiotic agents, as well as mobile genetic elements and even virulence traits that could potentially mobilize and rearrange once in the open environment. A graphic summary of the sections below is in Figure 1.

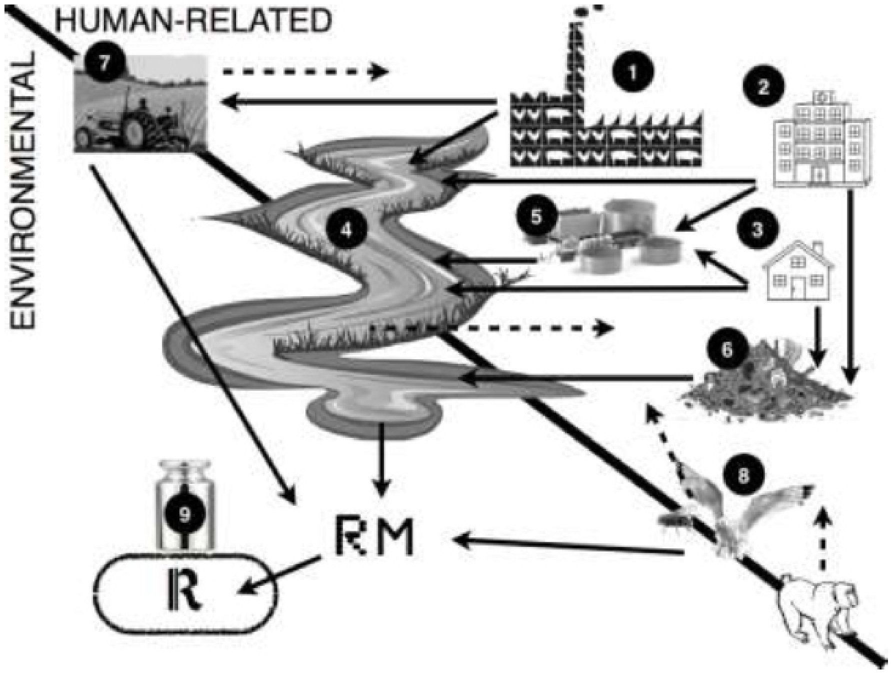

Figure 1. Resistance in the environment.

Bacterial resistance to antibiotics became a problem due to the human massive production and use of antibiotics; this is represented in the top-right side of the figure (human-related), mainly including the use of antibiotics in industrial farming (1) and other agricultural purposes; and the clinical use, both in hospitals (2) and outpatients (3). The main interface between urban or otherwise "human-related" environments, and open, "human-free" environments (bottom left side), are water bodies (4), that receive ARB/ARG in the discharge of wastewater from farms, hospitals and houses (either directly, or after treatment, in wastewater treatment plants (5)), and from leaching and runoff from garbage dumpsters (6). Also, manure from antibiotic-fed animals is applied directly to soils (7). Other "vectors" of ARB/ARG are flying animals (8). All these contribute to a pool of resistance genes, an "R" in dotmatrix font to represent its human-related origin; these genes are often linked to mobile elements, the "M", which facilitate their transfer to other microorganisms. On the other hand, environmental bacteria (bottom left) also carry ancient resistance genes (an "R" in old-fashion font), some that have already made their way to human pathogens, and many that do not. These environmental organisms are receiving loads of "new" resistance genes, along with mobile elements from human-made environments, and are under the selective pressure (9) of antibiotics, other antibacterial xenobiotics (e.g., disinfectants, non-antibiotic drugs with antimicrobial properties) and toxic metal ions that are also released by humans into the environment. The result of gene rearrangements, lateral transfer, and new combinations of old and new resistance genes, return to the human environment (dashed arrows) by the same water bodies, along with vegetables grown in fertilized soils, carried by flying animals, and perhaps even by the hunting and handling of wildlife.

3.1. Resistance already in the environment

As Julian Davies reported nearly fifty years ago [6], some ARG can be traced down to the organisms that produce antibiotics, most of them soil bacteria. Considering that nearly all antibiotics currently in clinical use derive from naturally occurring molecules (i.e., aminoglycosides, betalactams, chloramphenicol, fosfomycin, glycopeptides, lipopeptides, macrolides, rifamycins, tetracyclines, in alphabetical order), mechanisms that enable producing organisms to survive their own metabolites have existed for millennia. Some such mechanisms have made their way to clinically relevant bacterial species (e.g., [7,8]), through horizontal gene transfer, that then thrive under the selective pressure of ubiquitous antibiotic presence. However, many other ARG found in pathogenic bacteria do not seem related to those found in the respective antibiotic-producing organism. This apparent disconnection could be caused by "sampling bias", i.e., ARG do come from antibiotic-producing bacteria, just different from those used industrially to manufacture antibiotics.

In any case, an analysis of nearly 500 strains of soil Streptomyces, reports the presence of many "resistance" traits [9]; although many of them are the result of a poor methodology (e.g., arbitrary breakpoints for assessing resistance, inclusion of phenotypes most likely to be intrinsic resistance), it is clear that there is a large gene pool of resistance determinants in the environment.

The sole notion that antibiotics have been in the environment for millions of years should led to the inevitable conclusion that ARG are also ancient, in antibiotic-producing organisms, and/or in organisms naturally exposed to such antibiotics. Nevertheless, the fact that antibiotic resistance is ancient has been recently "re-discovered" by papers in top journals (e.g., [10]). Despite the known shortcomings of metagenomic approaches, discussed briefly above, these studies provide evidence supporting the existence of ARG much before of the release of industrial antibiotics into the environment. Another interesting finding is that many such "resistance" traits have never been reported in clinically relevant bacteria: perhaps this is a mere consequence of molecular analyses being performed only in a minority of clinical isolates; perhaps it is only a matter of time for such traits to travel into pathogenic bacteria; or perhaps HGT is not so powerful after all, and known examples of ARG originating in the environment are more the exception than a rule. Mobility elements in environmental bacteria are fewer, and far away from putative ARG, than in human pathogens [11]; this could point to a very limited mobilization of ARG from the environment, but also to a potential increase should the prevalence of mobility elements also increases in the environment.

In addition to older cases of ARG found in pathogenic bacteria that can be traced down to ancient genes, discussed above, there are a few examples of recently discovered determinants in clinical isolates that clearly have environmental origin. These cases could illustrate the dynamic nature of the ongoing evolution of resistance; but can also be simply the consequence of the evolution of the molecular methodologies we use to study it. In other words, they could be genes recently introduced into the resistome of human pathogens; or just recently discovered genes that have been there for a while. Perhaps the better example is the extended-spectrum beta-lactamase (ESBL) CTX-M. The genes encoding this enzyme originated from Kluyvera spp., a genus of soil bacteria; this kind of ESBL emerged globally in clinical isolates during the 1990's, to become the prevalent enzyme in enteric bacteria in many parts of the globe [7]. While the blaCTX-M gene is chromosomal in Kluyvera spp., it is almost always plasmid-borne in enterics, and such plasmids often also carry other Kluyvera's neighboring chromosomal genes [12]. This is an interesting example of an ancient resistance gene, of (yet) unknown function in the environment, from the chromosome of an organism that does not produce any antibiotic, jumping into a protagonic resistance role in human pathogens. Another example is the qnr group of plasmid-borne genes, mediating a low-level resistance to fluoroquinolones: these came from the chromosome of Shewanella algae, a water bacterium, and were first detected in the clinical environment by the late 1990's. This ARG has the additional puzzling feature that it provides protection against a group of synthetic antibiotics, which precludes the notion that it plays a role in the protection against, or in the synthesis of a naturally occurring molecule. Although some other natural compounds are, as quinolones, topoisomerase inhibitors, hence such ancient gene could have had a protective role against them [13], this is far from clear. Getting back to Shewanella, it has been recently proposed that one of the plasmid-carried genes mediating polymyxin resistance, mcr-4, also originated from the chromosome of this water bacterium [14]. In the end, and considering the short time since metagenomic studies arrived into resistance research, it is perhaps only a matter of time to find many other examples of ARG of environmental origin causing the clinical failure of antibiotics. After all, only about 1x10-21% of the total DNA on Earth has been sequenced [15].

3.2. Resistance being released into the environment

ARB/ARG selected for by the intensive use of antibiotics by human activities, mainly clinical and agricultural use, are released into the environment in a number of ways. The two most abundant sources of ARB/ARG related to human activities are wastewater and manure; however, resistance gets into the environment in many other ways, ranging from lixiviates and runoff from garbage and other wastes, to airborne carriage by flying animals, such as birds and even flies. Considering that clinical antibiotic usage, in countries where there is some measurement of it, typically ranges around 10–20 daily defined doses per thousand inhabitants per day (DDD/TID) [16], something between 75 and 150 million people each day is receiving an antibiotic. Considering that the average weight of human feces is about 120 g/day, and that half of that weight is bacteria, medicated people would be releasing 4.5–9 million kg of antibiotic-exposed bacteria into the environment daily (something in the order of 1021–1022 bacterial cells). Only a fraction of those organisms would actually be ARB, and many are killed shortly after abandoning their host, or during wastewater treatment; however, plenty of ARG are still released daily into the environment. Furthermore, most humans still live either, in rural settings or in cities without proper sewage and/or wastewater treatment plants. On the other hand, manure from antibiotic-fed animals are directly applied to soils; just the US, taken as an example, fertilize with such manure a surface equal to the whole of Portugal [17]. Environmental contamination with ARB/ARG is both, intensive and extensive.

The nature of these ARB/ARG released into the environment includes essentially the whole spectrum of clinically relevant organisms and genes, perhaps with the exception of those to fragile and/or released in minute quantities (e.g., multi-resistant Neisseria gonorrhoeae). The most critical resistances, such as metallo-beta-lactamase-mediated (e.g., the New Delhi Metallo-beta-lactamase, NDM) resistance to carbapenems [18], or the plasmid-mediated resistance to polymyxins [19], have been found in the environment. Other, more abundant ARB/ARG, such as ESBL-producing enteric bacteria, are much more commonly reported in different kinds of environmental samples. In the urban settings, both the hospital and domestic sewage contribute to the ARB/ARG: selection and release in hospitals is much more intense, as is the use of antibiotics, making for identifiable "hotspots"; but the amount of antibiotics used by outpatients is much larger, leading to an overall larger contribution. For instance, the prevalence of resistance in Escherichia coli isolated from the hospital and municipal sewage in Gothenburg, Sweden, was always higher in the former, but the differences were rather modest: resistance rates hospital/municipal were, for example, 19/10% for amoxicillin-clavulanate, 5/1% for ceftazidime, 12/5% for ciprofloxacin, 5/0.4% for tobramycin and 20/11% for trimethoprim-sulfamethoxazole. While 5.5% of the 721 hospital isolates produced ESBLs, only 1.8% of the 531 municipal isolates did [20]. In addition to the obvious elimination of resistant organisms in the feces and other bodily fluids of antibiotic-treated patients, clinical settings have an overall different microbiota than other built environments: a diminished microbial diversity, a shift towards gram-negatives, and an increased diversity in ARG [21]. In the end, the metagenomic analysis of ARG in sewage correlates with factors affecting the local prevalence of resistance in clinical isolates, and could be used as indicator of such prevalences worldwide [22].

Developing countries also tend to have more crowded cities, with deficient urban infrastructure (i.e., sewage, waste collection and manage, wastewater treatment) that make for further sources of environmental pollution by ARB/ARG. A couple of examples from Mexico, a middle-income developing country, with diminishing use of antibiotics but high resistance rates [23], could illustrate the point: wastewater running in open canals, and open-air dumpsters of bio-hazardous hospital waste (Figure 2), both represent a clear source of environmental pollution with ARB/ARG. Cities in poor countries tend to concentrate risk factors for exposure to pathogenic bacteria and their byproducts (e.g., pro-inflammatory lipopolysaccharides), as well as antibiotic resistance [24]. They also commonly have air pollution problems, due to poor regulation and/or enforcement of industrial contaminants, higher prevalence of old motor vehicles lacking maintenance, etc. Bacteria exposed chronically to these forms of atmospheric pollution have a number of physiological changes, some encoded by adaptive mutations [25], that could provide protection against antibiotics. Finally, it is important to realize that globalization applies also to microbes: ARB/ARG can cross frontiers, within people or animals, and also in ships [26] and airplanes [27]. Therefore, the consequences of poor regulation and managing of environmental pollution in developing countries will affect the whole globe.

Figure 2. Examples of unchecked release of ARB/ARG into the environment of developing countries.

Top: an open sewage running through an urban setting, Cartagena canal, in Ecatepec, State of Mexico; all sorts of solid garbage, animal carcasses and occasionally dead people are also dumped into this canal. Bottom: the backyard of a company that collect bio-hazardous waste from hospitals and other healthcare facilities, in Toluca, State of Mexico; this garbage is supposed to be incinerated, but the overload caused by the COVID-19 crisis made them to store the waste in an open yard for many days.

3.3. Wastewater treatment plants: a peculiar pre-release niche

While most of the ARB/ARG selected by human activities that are released into the environment make their way without further changes, those few that get trapped by wastewater treatment plants (WWTP) are particularly worrisome. WWTP are a "luxury item" mostly found in developed countries: 90% of WW is treated before release in the US and Canada, 66% in Europe, but only 14% in Latin America and less than 1% in Africa. WWTP were designed to reduce both, chemical pollutants and organic load, including bacteria; however, those processes were not instrumented having antibiotics and antibiotic resistance in mind. And while treatments do reduce significantly the bacterial load of WW prior to its release into the environment, those microorganisms that survive are a major cause of concern. Within WWTP bacteria from different sources (e.g., hospital- and community-acquired pathogens, along with commensal and saprophytic bacteria) are put together, concentrated in semisolid networks that enhance the cell-to-cell contact enabling horizontal gene transfer, all while being subjected to diverse chemical stressors (e.g., antibiotics and other drugs, disinfectants and other toxic xenobiotics, heavy-metals) that select for, and/or induce the transfer, rearrangement or expression of ARG. Viable bacteria that escape the treatment, and perhaps even free DNA containing ARG, could potentially be much more dangerous than the ones that enter the process. A couple of examples illustrate the results of WWT: in terms of antibiotic resistance prevalence, resistance to individual antibiotics went, from 9, 25 and 63% towards amoxicillin-clavulanate, chloramphenicol and rifampin, respectively, in Acinetobacter spp. isolates from raw sewage; to 38, 69 and 84% post-treatment; multi-resistance went from 33 to 72% [28]. Measuring ARG copies per milliliter, sul genes encoding resistance to sulfonamide antibiotics were reduced from 106–107 copies/mL in hospital effluent, to 105–106 copies /mL in WWTP effluent; but the ratio sul1/16S-rRNA increased from 3 to 8%, and resistant isolates to 8 or more antibiotics went from 30 to 60% [29]. The extensive nature of gene exchange and rearrangement of ARG within WWTP, especially those linked to IncP-1 plasmids, was analyzed in a landmark paper [30]. Among the things that can be assembled in these plants is an IncF, 120-kb conjugative plasmid found in one such site: resistance to ampicillin, chloramphenicol, erythromycin, kanamycin, neomycin, streptomycin, sulfonamides, trimethoprim, tetracycline and mercury, scattered between remnants of transposons Tn21, Tn10, Tn1 and Tn402, and insertion sequences IS26 and IS6100, and a class 1 integron [31].

In addition to the mere confluence of ARB, ARG, and selective/inducing agents in the WW, the likelihood of the chemical or physical processes used to reduce the bacterial load in WWTPs ending up enriching the content of ARB has been explored recently. For instance, ESBL-carrying E. coli isolated from WWTP effluent seem to be more resistant to UV-exposure than their non-resistant counterparts [32]. Results of "standard" treatments tend to be contradictory, as they are all but "standard"; hence some authors report ultrafiltration being more efficient than ozone treatment for the removal of pathogenic bacteria and their ARG from wastewater [33], while others report that ozone treatment is just as effective [34]. The whole issue has been recently reviewed [35], including the efficiencies of filtration, ozonization, UV-irradiation and chlorination. As the release of ARB/ARG in treated wastewater is increasingly concerning, efforts towards optimizing such treatments, aiming specifically at the removal of resistance, are now in course. However, it may take several years before an enhanced method is universally agreed upon, and many more to have it deployed in existing WWTPs. Meanwhile, it may be worth considering the risk/benefit balance of the treatment of wastewater.

4. PERSISTENCE OF ARB/ARG WITHIN THE ENVIRONMENT

Once released into the environment, ARB/ARG from human-related origin can follow many paths: from being rapidly killed, which is likely for many enterics not capable of surviving in open environments; to being acquired and become transient or permanent members of the microbiota of wildlife. If they survive long enough to interact with the surrounding microbiota, either soil/water or animal, the potential for gene rearrangement and exchange seems limitless. Mobile genetic elements, often carried by ARB coming from human-related environments (e.g., class 1 integrons are much more common in E. coli isolates from humans and urban environments [36]; and the presence of such elements in isolates from human sources have been increasing steadily during the "antibiotic era" [37]), can transfer themselves into environmental ARB, fostering the intra-cellular mobilization of ARG between chromosomes and plasmids. New "compilations" of ARG, genes mediating resistance to other biocides, virulence genes and/or mobile elements, can arise from these interactions, all happening under the selective pressure of a number of environmental pollutants released along ARB/ARG (see below). This was perhaps the path followed by blaCTX-M, qnr and mcr-4 genes, described above: all chromosomal genes of environmental bacteria ending up in conjugative plasmids of human pathogens.

Genes can be mobilized intra- and inter-cellularly. Intra-cellular mobilization typically includes the movement of genes from chromosomes to plasmids and vice versa; this could be accomplished by transposons and integrons, that mediate several variations of "non-homologous" recombination. Plasmids are known to act as "collections" of transposons, often gathering several of these mobile elements. Integrons, on the other hand, "collect" gene cassettes, which frequently contain ARG. Inter-cellular mobilization, or horizontal gene transfer, is typically grouped into three categories: acquisition and expression of free DNA (transformation), cell-to-cell transfer of DNA (conjugation), and viral-mediated DNA transfer (transduction). Overall mechanisms have been extensively reviewed before (e.g., [38,39]). The only known mechanism of fully self-encoded mobilization is conjugation: conjugative elements, plasmids or integrated conjugative elements (ICEs) carry the genes that mediate the whole process. The release of transposons, integrons and conjugative plasmids, frequently carried by ARB from human-related sources, enable the gene rearrangements and mobilization discussed earlier. Along with these elements, transduction also plays a significant role; phages are perhaps the most abundant organisms on Earth, and a calculated 1x1023 phage infections occur per second [15], making this rather "accidental" mobilization actually inevitable. Transformation is supposedly limited by the short lifespan of DNA in open environments, the small number of (known) bacterial species capable of achieving transformation competence, and the need for a minimum sequence homology both, for DNA uptake, and for recombination leading to incorporation. Nevertheless, transformation is recognized as a means for transfer of ARG between clinically relevant bacteria, such as pneumococci; it is certainly possible for it to also play a role in the spread of ARG in some environments, soils in particular. This has been proven possible around the aadA gene conferring streptomycin resistance used in the construction of transgenic tobacco plants [40,41]. Considering that a significant amount of extracellular DNA can be recovered from soils [42], the likelihood of transformation as means of lateral transfer of ARG is certainly there.

ARB/ARG have been found in open, "human free" environments, wherever they have been searched for: water bodies, soils and wildlife [4]. Of course, the closest they are to human influence, the higher the prevalence and diversity of resistance traits. Culture-based methods have been rapidly displaced by metagenomic technologies that appear to be much more powerful. This is a mistake, as culture-based assessments can provide much more information on the actual origin and risk of detected ARG [43]. For instance, the detection of an ARG in a metagenomic analysis of remote environments could fail to assess if such a gene is indigenous, or was introduced from human-related sources. The risk posed by such an ARG can therefore be missed or overstated. Culture-based and metagenomic approaches are complementary.

5. ANTIBIOTICS AND OTHER BIOCIDES IN THE ENVIRONMENT

Although the aim of this review is not to analyze the environmental pollution by antibiotics and other biocides, it is necessary to, at least tangentially, include some remarks. Antibiotics dispensed to people and animals are excreted in active form in about 70% of the total administered amount (this, of course, is a coarse estimate, that varies widely between antibiotics and animal species receiving them). These antibiotics are also discharged into wastewater, manure and garbage, along with ARB; some of them are rapidly decomposed, such as beta-lactams, while others can survive for many years in waters and soils. Some modeling predict that, should reduce prescribing of antibiotics be the only way to reduce antibiotic pollution of waters, it would be necessary to reduce in 77% the prescription of macrolides, and in 85% the prescription of fluoroquinolones, to reach non-selective concentrations in wastewater [44]. Pharmaceutical companies, particularly those in developing countries, release massive amounts of antibiotics in untreated wastewater, sometimes reaching concentrations similar to those found in the blood of treated patients. Antibiotics are released directly into the aquatic environment by aquaculture; although some of these practices are done in confined tanks, other are done in cages or nets within natural water bodies. About 10,000 tons of antibiotics are used for aquaculture worldwide [45]. Non-antibiotic drugs, that are also released into the environment via wastewater, can also exert effects upon pathogenic and environmental bacteria [46]; while this has been extensively reviewed before, a couple of recently reported examples can illustrate the issue: (a) ticagrelor, an “antiplatelet” drug, has measurable antibacterial activity [47]; and (b) carbamazepine, an anticonvulsant, promotes horizontal gene transfer [48]. While drug pollution of water bodies is a growing cause of concern, almost nothing is known about the effects of such pollution upon bacterial communities.

In addition to drugs, antibiotics or not, a large number of other chemical agents can affect microbial physiology in ways that are relevant to the issue at hand. Disinfectants are a clear example: quaternary ammonium compounds do select for the presence of class 1 integrons, that often carry the qac genes encoding low-level resistance to such agents; bacteria isolated from environments contaminated with these disinfectants carry integrons more often than those from disinfectant-free environments [49]. Triclosan, on the other hand, while not actually selecting for resistance, can induce antibiotic tolerance [50], which in turn can facilitate the acquisition of canonic resistance. Other biocides, such as herbicides, can also affect bacterial susceptibility towards antibiotics: paraquat act as a redox-cycling compound, inducing oxidative stress responses that also protect against antibiotics [51]; glyphosate and dicamba modify the response to antibiotics in E. coli and Salmonella, increasing susceptibility to some, decreasing it to others [52]. Metal ions have bactericidal properties, and there are many genes that confer resistance towards those agents, some linked to ARG. Mercury-resistance genes mer are well-known examples, but also cadmium/zinc resistance genes have been found linked to macrolide and aminoglycoside resistance genes. Bacteria carrying both ARG and metal-resistance genes are common among clinical isolates, less in isolates from humans and domestic animals, and very rare among environmental isolates; plasmids carrying both kinds of determinants are also more likely to be conjugative [53]. Interestingly, while there are reports of metal ions co-selecting and inducing horizontal gene transfer [54], zinc and copper specifically inhibit the expression of conjugative genes, hence diminishing such lateral transfer [55].

Again, while this review does not focus on antibiotic pollution, it is a crucial piece of the puzzle to understand the consequences of the release of ARB/ARG into the environment.

6. RISKS OF ENVIRONMENTAL POLLUTION BY ARB/ARG

While writing a news piece about an article on the detection of ARB in the feces of wildlife of a Mexican forest [56], one of the external scientists contacted for his opinion stated that “antibiotic resistance is everywhere and most people that make a big deal out of finding it don’t understand the bacteriology”. This is, of course, partially true: as has been reviewed above, resistance, in general, is as ancient as antibiotics themselves, so it is somehow to be expected to find ARB in the microbiota of non-domesticated animals. However, to find ESBL-producing enteric bacteria among free-living jaguars, for instance, is peculiar for two main reasons: (a) some ESBL-encoding genes, although ancient, did not originate in Enterobacteriaceae (see above), therefore their presence in this bacterial group is at least indicative of horizontal transfer of resistance genes within the environment and in the apparent absence of selective pressure; and (b) if the gene or the organism was acquired from human-related sources, it would be a remarkable feat for a not-so-common trait among communityacquired pathogens to find its way to an animal living some kilometers away from the nearest human settlement and, again, in the absence of known selective pressures. Nevertheless, this or any other finding related to ARG/ARB in the environment could seem like an interesting subject for the microbiological, molecular biological, or environmental sciences, but with scarce clinical impact, if any. After all, if such a resistant organism is to cause an infection in a wild animal, it is very unlikely that the fate of the infection or the infected would be any worse because of the resistance trait. The risk for a human to get infected by a resistant pathogen coming from the environment is a real possibility, but apparently limited to some groups at risk, from people living in the vicinity of wastewater canals, via aerosols and flies, or through contaminated wounds; to fishermen and agricultural workers exposed to polluted environments; to perhaps even people that came in proximity to wildlife carrying such resistant bacteria. Among the recognized pathogens that spread from the environment or wildlife, most are viruses and only a few are bacteria (e.g., Borrelia burgdorferi, Yersinia pestis, Mycobacterium bovis). Deforestation, habitat fragmentation, and climate change are among the factors that tend to increase the risk of such transmission to occur [57].

However, those bacterial pathogens seldom carry resistance genes. In any case, the risk would be much less than that of acquiring an infection by a multi-resistant microorganism within a hospital or other healthcare facility, where resistance is much more common. But that is not the whole picture. The immediate effects of ARB/ARG release into human-related environments would not be discussed here. Obviously, vegetables grown in manured soils, and fish grown in antibiotic-laden waters carry ARB that can directly cause infections, or at least contribute ARG to the microbiota of exposed people. Globalization makes it possible for such foodstuff to travel across the world, affecting people even in countries where the use of antibiotics is better regulated. Birds, flies, cockroaches and rats can carry ARB from farms or landfills, contaminating environments not supposed to have such organisms. People living close by, or even within heavily polluted environments, such as in the vicinity of irrigation canals carrying raw WW, are more likely to be affected by the increased presence of ARG. However, in the end, this would all be part of a humanrelated environment: the damage would be contained within.

The changes induced both, by the release of massive amounts of human commensal and pathogenic bacteria, often loaded with ARG, and of selective chemical agents, into the environment, ought to change the microbiota at the receiving end of the process. In soils, where naturally occurring antibiotics play signaling roles rather than "chemical warfare" [58], the introduction of organisms capable of destroying such signaling molecules can potentially disrupt delicate ecosystems. The simultaneous presence of ARG in conjugative plasmids, and of minute concentrations of antibiotics known to induce conjugative transfer [59], could enhance the chances of ARG being acquired by indigenous microbiota. Changes in soil microbiota could affect geochemical processes as important as nitrogen fixation [60]. Environments receiving even minute concentrations of antibiotics (below those considered as "predicted no effect concentrations", PNEC, a figure established based on effect of metazoan species) could have their antibiotic-susceptible microbiota reduced and substituted by ARB from human-related origins; this could in turn affect the ecosystem "services" these microbial communities provide (e.g., nutrient cycling, metabolism and degradation of organic and inorganic compounds). There is also, of course, the possibility of such indigenous microbiota to acquire those ARG introduced into the environment, creating unknown new risks [61]. Even saprophytic bacteria, such as Pseudomonads, that have been considered as limited participants in the "gene internet" deployed by plasmid-mediated horizontal gene transfer, do carry a lineage of mobilizable plasmids bearing, among other things, IMP, BIM and VIM metallo-beta-lactamases [62]. The transfer of the gene encoding another of these enzymes, NDM-1, from enteric bacteria into P. aeruginosa and Acinetobacter baumannii occurs readily in biofilms [63], a common way of life of bacteria in the environment.

The effects of changes in the microbiota of wildlife could be even more dangerous. Commensal or pathogenic bacteria in humans are more likely to survive within another mammal than in the open environment, and also more likely to find phylogenetically related organisms in the indigenous microbiota of such animals, with which gene exchange may be more successful [11]. Considering the extensive physiological, metabolic and even behavioral impact of changes in the human microbiota, there is every reason to suspect the same in wild animals. A recent report of microbiota changes affecting learning processes in mice [64] illustrates this. Animals exposed to ARB from humanrelated environments can suffer such changes. And while the impact of the acquisition of antibiotic resistance may have little direct effect upon the affected animal's health –after all, wild animals are not likely to receive antibiotic treatments, the linkage of some of these resistance determinants with virulence genes could potentially cause new or more severe infections in wildlife.

In the end, for many people the most concerning possibility is that, as did happen with CTX-M beta-lactamase and other resistance traits that originated in the environment, other unknown or perhaps even yet inexistent threats do reach us in the future, in the form of untreatable infections. This can happen in a wide variety of ways: (a) dangerous ARG have been detected even in tap water (e.g., [65]), indicating that ARB/ARG dumped in water bodies, and perhaps even ancient, naturally occurring ones, can reach us through water faucets; (b) handling and eating wildlife can be a risk of exposure to resistant pathogens; this might sound as limited scenarios, of "sport" hunters (who likely deserve the risk) or remote communities, but even free-living marine fish carry ARG, mostly localized in mobile elements [66]; (c) flying animals can carry ARB and cross the faint line between human-related and "human-free" environments; while the main risks these animals are associated with is the carriage of ARB/ARG from, for instance, countries that keep using antibiotics agriculturally to those that have banned these practices [67], they could also bring ARB/ARG "concocted" in the open environment to our doors.

7. CONCLUDING REMARKS

Once the COVID-19 crisis is over, we would come out from the rubble to find antibiotic resistance still waiting for us, perhaps even at an increased pace. While the evidence of the accelerating emergence of new resistance is non-conclusive [68], there are many reasons to think it may be so. The presence of resistance in the environment may very well be an important factor contributing to this phenomenon. With pharmaceutical companies still demanding "incentives" to return to research and development of new antibiotics [69], it is crucial to assess the presence of resistance in the environment, and to stop releasing more into it.

Conflict of interest

The author declares no conflicts of interest in this paper.

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Home composting in remote and cross-border areas of the In.Te.Se. project

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ABSTRACT

The In.Te.Se. project - Innovation Territory and Services, for waste management in scattered areas is an Interreg V-A France Italy (ALCOTRA) project, financed within the framework of European cross-border cooperation programmes, in the Alpine region between France and Italy. On the subject of the local exploitation of organic waste, it permits the experimentation of home composting in scattered and cross-border areas in the Italian territories of the Province of Cuneo (Consorzio Servizi Ecologia e Ambiente, CSEA) and in the French areas of the PACA Region (Syndicat Mixte de Traitement des Ordures Ménagères des cantons du Guillestrois et de l'Argentièrois SMITOMGA), through the use of individual and collective, manual and electromechanical composters.

During the project it is estimated that a quantity of organic waste equal to about 2% of the not sorted waste produced in 2019 has been valorised, in 3 municipalities of CSEA and 23 municipalities followed by SMITOMGA where a separate collection circuit does not exist and it is conferred with the general unsorted waste. Overall, 31.72 tons of compost are obtained. The environmental balance deriving from the cooperation of the territories also makes it possible to estimate a negative balance of CO2 produced, with 3212.78 kgCO2 avoided. The economic assessment of not sending the organic component for disposal produced a saving for the two communities as a whole of €10,397.56, involving only 15% of the total population in the municipalities investigated. At the same time, a comparison with a separated collection system for the organic matter, determines the saving of €27,295.73 considering the all tested area. The implementation of this good practice has the potential to achieve interesting results from an environmental, social and economic point of view and to be extended to further portions of the territory and has demonstrated the successful choice of cross-border cooperation and the diversification of applied techniques.

Keywords: cooperation; organic waste; composting; exploitation; compost; home composting; collective composting

1. INTRODUCTION

The In.Te.Se. project, France-Italy, is financed by the INTERREG V-A Alcotra Programme 2014–2020, European Regional Development Fund, under priority axis 1 APPLIED INNOVATION (innovation and development of innovative cross-border services) and involves 6 partners: Consorzio Servizi Ecologia Ambiente (CSEA) project leader, Consorzio Albese Braidese Rifiuti (CoABSeR), E.R.I.C.A. soc. coop., Communauté de Communes du Pays des Ecrins (CCPE), Syndicat Mixte Intercommunal du Traitement des Ordures Ménagères du Guillestrois et de l'Argentièrois (SMITOMGA), Communauté de Communes du Guillestrois et du Queyras (CCGQ).

The project defines an innovative model for the management of household waste, focused on Reduction, Reuse and Recycling implemented in the Alpine area and in scattered areas and which permits improving the quality of the service provided in the area and increasing its effectiveness and efficiency in economic and environmental terms.

The main experimental activities carried out by the project concern the themes of prevention, reuse, and innovation in pre-sorted waste collection and in particular self-composting. Self-composting, carried out in scattered areas and for large producers, makes it possible to exploit organic matter, transformed into compost, eliminating the wet waste collection service or diverting it from the unsorted waste stream, enabling users to manage waste directly and independently and reducing the impacts generated by it. The project involved 1070 users and 26 municipalities.

2. MATERIALS AND METHOD

The self-composting experiment was carried out in two different ways:

- Individual composting, carried out individually by a single user through his/her own manual composter;
- Community composting, carried out by several users in conjunction with one another, through two types of composters: manual and electromechanical.

The activity was carried out in mountain and remote areas and led to the involvement of residential and non-residential users in 26 municipalities, 3 Italian and 23 French, belonging to the project areas.

None of the municipalities where the experiment was carried out had a waste collection service dedicated only to the organic component, which is discarded by users with unsorted waste.

Table 1 shows the indication of the consortia and local authorities involved and the resident population, in Table 2 the number of users actually involved, the type of composting carried out and the type of composter used for household waste treatment is indicated for each municipality.

Table 1. List of the competent consortia and territorial authorities involved in the project action and demographic data.

Competent consortium/ organisation	Resident population involved in the experiment (number of inhabitants actually involved)	Total resident population in the municipalities where the experiment is realised
CSEA (3 municipalities)	345	1306
SMITOMGA (23 municipalities)	2024	14736
TOTAL	2369	16042

Table 2. List of the involved areas, relative users (families, actually involved in the experiment) and general type of self-composting and composter.

Municipality	Consortium	Number of users involved	Type of self-composting done	Type of composter used
Melle	CSEA	115	Community self-composting	Electromechanical
Murello	CSEA	25	Community self-composting	Electromechanical
Ostana	CSEA	10	Community self-composting	Electromechanical

Municipality	Consortium	Number of users involved	Type of self-composting done	Type of composter used
Ceillac	SMITOMGA	62	Individual and community self-composting	Manual
Champcella	SMITOMGA	26	Individual and community self-composting	Manual
Château-Ville-Vieille	SMITOMGA	6	Individual and community self-composting	Manual
Mont-Dauphin	SMITOMGA	20	Individual and community self-composting	Manual
Puy-Saint-Vincent	SMITOMGA	8	Individual and community self-composting	Manual
Saint-Clément	SMITOMGA	11	Individual and community self-composting	Manual
Abriés-Ristolas	SMITOMGA	29	Individual and community self-composting	Manual
Aiguilles	SMITOMGA	14	Individual and community self-composting	Manual
Arvieux	SMITOMGA	14	Individual and community self-composting	Manual
Molines en Queyras	SMITOMGA	18	Individual and community self-composting	Manual
Réotier	SMITOMGA	17	Individual and community self-composting	Manual
			self-composting	
Vars	SMITOMGA	12	Individual and community self-composting	Manual
Risoul	SMITOMGA	39	Individual and community self-composting	Manual
Saint-Crépin	SMITOMGA	100	Individual and community self-composting	Manual
Saint-Martin-de-Queyrières	SMITOMGA	15	Individual and community self-composting	Manual
St. Véran	SMITOMGA	15	Individual and community self-composting	Manual
Eygliers	SMITOMGA	116	Individual and community self-composting	Manual
Freissinières	SMITOMGA	6	Individual and community self-composting	Manual
Vigneaux	SMITOMGA	19	Individual and community	Manual
			self-composting	
La Roche de Rame	SMITOMGA	28	Individual and community self-composting	Manual
Guillestre	SMITOMGA	151	Individual and community self-composting	Manual
Vallouise-Pelvoux	SMITOMGA	70	Individual and community self-composting	Manual
Argentière-la-Bessée	SMITOMGA	124	Individual and community self-composting	Manual
TOTAL		1070	-	-

The composters used for the activity and the relative technical details are described in Table 3.

Table 3. Types of composters used and characteristics.

Type of composter	Treatment capacity	Model	Number of installations
Electromechanical community composter installed in wooden housing	25 t/year	laCompostiera.it – Sartori Ambiente	1
Electromechanical community composter installed in wooden housing	10 t/year	Compost 10 - Ecopans	1
Electromechanical community composter installed in wooden housing	5 t/ year	Compost 5 - Ecopans	1
Manual community composter made of wood	600l–800l	Gardigame classique NF024 - Gardigame	31
Manual individual composter made of wood	300 l	Gardigame classique NF024 - Gardigame	610
TOTAL	-	-	644

Electromechanical composters are semi-automatic machines, fed by connection to the power mains and consist of two chambers, the first one for treatment and the second one for maturation, in which the organic material passes through automatically to ensure its complete transformation into compost. The equipment does not need to be connected to the sewer network because the liquids produced are recirculated inside the chambers. The machines are equipped with automatic mixers which ensure correct and continuous turning of the material inserted inside them, fans which provide the necessary supply of oxygen to the process and automatic dosing units for the pellets (structuring effect).

All models are also equipped with safety devices and automatic stoppage in case of danger or anomaly, to ensure the safety of users during all the operating phases of the machinery. They have ventilation systems and dedicated openings to allow air intake.

For the composter model laCompostiera. it there is an initial chamber of smaller dimensions (10 litres) intended for the placement of waste by the user, equipped with a mechanical shredder to shred the waste and connected to the pellet storage department (structuring effect), inside which it is added as required. The composter is equipped with a control panel through which it is possible to start the transit of the material from the first to the second chamber and to proceed with the withdrawal of the compost, as well as to set and control the parameters to trigger the correct aerobic biodegradation process. Using this panel, it is also possible to remotely access the machine data.

The Ecopans composter models do not have a shredding chamber, so the organic waste is inserted by the user directly into the first treatment chamber. The machines are equipped with control panel and temperature sensors.

The manual community composters, made of wood, Gardigame classique NF024 model, consist of two separate treatment sections closed by an upper wooden door, so that the biodegradable material contained inside is moved manually by the operator from one compartment to the next, based on the degree of maturation of the waste inside. From the second maturation chamber the compost is then extracted once it has been obtained. Individual wooden composters of the same model consist of a single module.

For the electromechanical composters installed in the wooden housings, a card or access key has been provided only to the users interested in using it.

For wooden composters located outdoors, there is no type of access control or limit to the same. All community composters are supervised by appointed and trained staff, who take care of management.

The compost produced is currently made available to the community for private use, with possible future uses in local farms. The use of compost as a soil improver causes a reduction in the use of fertilizers.

The period of waste treatment in the composters varies according to the models, as specified below:

Table 4. Period of treatment of organic waste for each composter.

Composter model	Length of stay in first chamber	Length of stay in second chamber	Total period of treatment to obtain compost
laCompostiera.it – Sartori Ambiente	20 days	20 days	40 days (minimum period indicated for the model, increased up to 60 days in operation)
Compost 10 - Ecopans	30 days	30 days	60 days
Compost 5 - Ecopans	30 days	30 days	60 days
Gardigame classique NF024 – Gardigame – modulo doppio	at least 30 days	at least 30 days	at least 60 days
Gardigame classique NF024 – Gardigame – modulo unico	single chamber	single chamber	at least 60 days

The period of experimentation is different depending on the sites, since the installation and startup of the composting activity does not take place simultaneously. Table 5 shows the period of observation and monitoring of the experimentation, referred to each site.

Table 5. Period of experimentation monitoring.

Composter model	Experimentation period	Total duration of experimentation
laCompostiera.it – Sartori Ambiente	December 2019 – September 2020	10 months
Compost 10 - Ecopans	March 2020 – September 2020	7 months
Compost 5 - Ecopans	December 2019 – September 2020	10 months
Gardigame classique NF024 – Gardigame – double module	September 2019 – September 2020	12 months
Gardigame classique NF024 – Gardigame – single module	September 2019 – September 2020	12 months

The use of electromechanical composters results in electricity consumption, that allow them to function properly. The average annual consumption values for the models used are shown below.

Table 6. Electricity consumption attributed to electromechanical composters.

Composter model	Electrical annual consumption (kWh/year)
laCompostiera.it – Sartori Ambiente	900
Compost 10 - Ecopans	900
Compost 5 - Ecopans	900

The following assumptions are also considered for the monitoring of the trial:

- The average per capita production of organic waste, suitable for home composting, is 50 kg/inhabitant per year in France [1];
- Waste is discarded on average once a week by users [2,10];
- The average composition of users in Italy is 2.3 persons/user [3], while in France it is 2.2 persons/user [4];
- The yield of compost production starting from organic waste in a range between 20% and 40% of the initial mass, so an average value of 30% is considered [5,6,10];
- The average specific mass of compost falls within the range 0.3 – 0.4 kg/l, so an average value of 0.35 kg/l has been used for the conversion from volume to mass of compost [5,6];
- The carbon sink effect in the soil is considered with a CO_2 storage index equal to −17.6 kg CO_2/t organic waste sent for composting, considering the methodology applied to calculate the CO_2 balance determined by the use of compost in agriculture [7];
- The emission mitigation factor following the non-use of fertilizers for the land is set equal to −18.7 kg CO_2/t organic waste sent for composting, for which the emissions avoided for the production of fertilizer and for the production of ammonia and nitric acid are considered, seeing the methodology applied to calculate the CO_2 balance determined by the use of compost in agriculture [7];
- The greenhouse gas (GHG) emission factor of the electricity sector for the production of electricityis 0.377 kgCO_2/kWh [8]
- The average cost of CO_2 is set at 24.18 € / t CO_2, calculated on the average for the period September 2019 – September 2020 [9].

For the 3 sites of Melle, Murello and Ostana, the volumetric or mass measurement of the compost produced was directed, by the municipalities, with subsequent sending of the data to the reference consortium (CSEA). From the produced compost data, the data relating to the organic waste conferred by users were obtained.

For the 920 sites of all the French communities, the definition of the compost produced was carried out by estimate, based on the assumptions made, and the definition was also made of the flow of organic waste to the composters.

The average costs per tonne for the disposal of unsorted waste, containing the organic waste in absence of the trial, at the CSEA and SMITOMGA sites for subsequent economic analysis are shown below:

- Average cost for the disposal of unsorted waste containing organic waste at CSEA: 109.60 €/ton of waste [11];
- Average cost for the disposal of unsorted waste containing organic waste at SMITOMGA: 97.90€/ton of waste [12,13].

On the other hand, if we assume the average cost of creating a dedicated organic waste collection service as an alternative to the combined collection with unsorted waste, the parameters to be considered would be the following:

• Average cost for the collection of organic waste at CSEA: 132.00 €/ton of waste [11];
• Average cost for the treatment of organic waste at CSEA: 88.00€/ton of waste [11];
• Average cost for the disposal of unsorted waste containing organic waste at SMITOMGA: 174.00€/ton of waste [12,13];
• Average cost for the treatment of organic waste at SMITOMGA: 86.00€/ton of waste [12,13].

3. RESULTS

The results obtained through community composting and individual composting in the Italian and French communities are presented below, with regard to each site involved in the experiment, in terms of the quantity of organic waste conferred and the compost consequently obtained.

Table 7. Quantity of organic waste conferred to composters and compost produced in Italy.

Composter model	Conferred organic waste (kg)	Compost produced (kg)
laCompostiera.it – Sartori Ambiente	3465	1050
Compost 10 - Ecopans	578	175
Compost 5 - Ecopans	429	130
TOTAL (kg)	4472	1355

Table 8. Quantity of organic waste conferred to composters and compost produced in France.

Composter model	Conferred organic waste (kg)	Compost produced (kg)
Gardigame classique NF024 – Gardigame – modulo doppio	67,100	23,485
Gardigame classique NF024 – Gardigame – modulo unico	34,100	11,935
TOTAL (kg)	101,200	30,360

Overall, at 30th September 2020, it is estimated that 105.67 tonnes of organic waste were not conferred to the public service and were home composted with the production of 31.72 tonnes of compost. This compost can be used directly by users in the municipalities involved as a soil improver for gardens and vegetable gardens.

As far as the economic analysis is concerned, Table 9 shows the savings obtained from the nondisposal of organic waste, which was not brought to the unsorted waste collection circuit.

Table 9. Savings deriving from the non-disposal of organic waste in Italy and France.

Competent consortium/organisation	Savings estimated during the course of the project (€)
CSEA	490.08
SMITOMGA	9907.48
TOTAL (€)	10,397.56

On the basis of the relative unsorted waste disposal costs, the flow of which also includes biodegradable waste of household origin, as at the 30th September 2020, it is estimated that the experiment could produce a total saving of €10,397 if the Italian and French quotas are added together. If, on the other hand, we compare the composting activity with the creation of a collection circuit dedicated only to the fraction of organic waste, the resulting expenses for the collection, transport and treatment service for each consortium would be as follows:

Table 10. Costs deriving from a possible dedicated collection system and related treatment phase for organic matter in Italy and France.

Competent consortium/organisation	Costs estimated during the course of the project (€)
CSEA	983.73
SMITOMGA	26,312.00
TOTAL (€)	27,295.73

The establishment of a specific collection system for the organic matter and its proper treatment as an alternative to the composting would cost €27,295.73 for the two communities.

By carrying out the balance of CO_2 emitted following the operation of the electromechanical composters and CO_2 avoided thanks to the carbon sink effect of the organic carbon sequestered in the compost and the CO_2avoided following the non-use of fertilizers, the following results are obtained:

Table 11. Balance of CO_2 equivalent resulting from the use of compost.

Action	Quantity of CO_2 generated/avoided ($kgCO_2$)	Reference territory
Electricity energy consumption	+623.09	CSEA
Carbon sink capacity	−78.70	CSEA
	−1781.12	SMITOMGA
Mitigation for the non-use of	−83.62	CSEA
fertilizers	−1892.44	SMITOMGA
TOTAL BALANCE ($kgCO_2$)	−3212.79	-

Overall, it is estimated that the individual and collective home composting activity carried out until 30th September 2020 avoided the emission of −3212.79 kg of CO2, which economically correspond to an environmental benefit of −77.69 €.

If we consider the budget divided by territory, in the case of CSEA, with the results obtained so far, we would not obtain a saving of carbon dioxide emitted and, on the contrary, a production equal to 46078 kg would result, with an environmental cost of € 11.14.

4. DISCUSSION

The implementation of home composting has made it possible to exclude from the unsorted waste collection circuit a quantity equal to 4.47 tonnes of waste for the municipalities of the CSEA areas and 101.2 tonnes for the areas under SMITOMGA management.

Comparing these locally reused waste flows with the flow of unsorted waste collected during 2019 in the municipalities involved, it can be seen that:

- the quantity of waste sent for home composting in the CSEA area represents 1.6% compared to the dry residual waste conferred during 2019;
- the quantity of waste sent for self-composting in the SMITOMGA area represents 1.9% compared to the dry residual waste collected in 2019.

Comparing the estimated data relating to compost locally produced by users and referring it only to the population actually involved in the experimentation (2369 people), on the basis of the average number of components per user depending on the area involved, we see that the per capita amount of compost produced per inhabitant in Italy is equal to 3.93 kg/inhabitant and for France equal to 15.00 kg/inhabitant during the project.

The environmental benefit deriving from the practice of self-composting translates into the subtraction of 3212.79 kg of CO_2, corresponding to −3.00 kg /CO_2 for users specifically involved in the experiment (1070 experimental users) and −0.20 kg CO_2/ inhabitant considering the entire population present in the test areas (16,042 inhabitants). If the balance was broken down by territory, in the case of CSEA an environmentally positive benefit would not be achieved, or in the period considered, there would be a production of CO_2 resulting from the implementation of composting using electro mechanical composters, equal to 460.68 kg. Cooperation is therefore a fundamental success factor, together with the choice to diversify the technologies used in experimentation.

From the economic analysis, it is obtained instead that the savings obtained from the non-disposal of organic waste together with the dry residue, referring to the entire population of the municipalities involved in the project action (1306 inhabitants for CSEA and 14,736 for SMITOMGA), is equal to 0.38 €/inhabitant for the Italian territories and on 0.67 € /inhabitant for the French municipalities. The savings obtained are divided on the overall population of the municipalities where the experiment is realised for each Consortium and not only on the only involved one, because the costs of the service is generally referred to all the territory.

On the other hand, the comparison with other alternative solutions, such as the separate collection of organic waste with a dedicated system, would again lead to additional costs, saved to the communities through self-composting and amounting to €27,295.73 for the overall test area. It is possible to estimate a saving of 0.75€/inhabitant for CSEA territories and of 1.79€/inhabitant for SMITOMGA territory.

To these values it is possible to add the savings deriving from the overall CO_2 balance, meaning it as a joint parameter of the project areas, which converts into a saving of € 77.69 globally, or equal to € 0.005/inhabitant (out of the total of 16,042 inhabitants).

At the same time, by separating the carbon dioxide balances between the territories, a cost of € 10.97 would be obtained for the CSEA area of competence (equal to € 0.008/inhabitant of the test area) and a saving of € 87.43 for municipalities followed by SMITOMGA (corresponding to −0.006 €/inhabitant of the test area territory).

The amount of CO_2 generated with the two collection systems (with unsorted waste and with dedicated collection of the organic matter) was not calculated due to the multiple variables existing and the complexity of the context considered.

5. CONCLUSION

The areas investigated with the experimentation of the In.Te.Se. project are scattered and remote communities, where the collection service dedicated only to organic waste is not envisaged. Such waste is consequently conferred together with the residual dry waste, conveyed for disposal without recycling.

The implementation of home composting in these areas, with particular reference to the 3 municipalities in the CSEA territory and the 23 municipalities covered by SMITOMGA, made it possible to avoid sending for disposal a percentage equal to about 2% of the unsorted waste totally produced by the same areas, a figure comparable to that of 2019 and involving only 15% of the population living in the same areas.

The environmental benefit deriving from the implementation of the experimentation is determined by the cooperation between the territories, which offset the carbon dioxide emissions produced by the electromechanical composters, allowing for an overall balance of −3,212.79 kgCO2, corresponding to −3 kgCO2 per user involved.

From the experimentation, it is estimated that a total of €10,597.56 will therefore be saved, due to the non-disposal of biodegradable waste with the residual dry waste, which spread over the entire population of the municipalities involved in Italy and France, amounts to a saving of €0.67 per inhabitant. Comparing to a separate collection system with organic waste collection, the saved amount would raise to €27,295.73, corresponding to €1.70 per inhabitant for the global test area considering together CSEA and SMITOMGA territories.

To these values would be added € 77.69, corresponding to the savings deriving from the negative balance of CO2 emissions (€ 0.005 saved / inhabitant).

The application of this good practice has shown to have valid potential for the local treatment and enhancement of organic matter carried out directly by users, also in a collective and collaborative form, as well as to reduce the environmental impacts of this fraction of waste on the overall cycle, dedicating them an alternative channel to collection with residual dry waste or to the need for an ad hoc collection and transport service with treatment. Also from an economic point of view, already from the first months of experimentation it was possible to quantify the achievable savings.

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Sustainable Built Environment in Mid Sweden: Case Study Based Models for Sustainable Building and Construction Processes

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ABSTRACT

A large proportion of the earth's resource turnover is caused by building and construction activities. There are also many health and safety problems related to the built environment. All these effects are contained in the concept of sustainability. In order to reduce the impact of the built environment it is important to plan for higher ecological, social, economic and cultural sustainability in all stages of the building and construction planning process. A problem is that these processes are complex with many actors involved in different stages. The complexity can be handled with an integrated planning model that is based on continuous dialogue during the process between the actors involved. Case studies of construction projects show that such models for continuous experience feedback can work in practice. The purpose of this paper is to study and analyze sustainable construction processes with regard to clear goal formulation and continuous follow-up of the sustainability parameters. It is also to develop a general model for managing sustainable construction and housing processes regarding ecological, economic, social and cultural dimensions. The model is the result of action research-oriented case studies carried out within the framework of the EU-project Sustainable Built Environment in Mid Sweden (SBEMS).

Keywords: sustainable built environment, sustainable building, construction processes, health and safety, leadership, work environment.

1. INTRODUCTION

1.1. Background

This article is based on the results presented in the final report for the EU project Sustainable Built Environment in Mid Sweden (SBEMS) [1] that was implemented 2016–2019. That goes especially for the parts of the report for which the authors of this article are responsible.

Mid Sweden is a collective name for the two regions, Västernorrland and Jämtland / Härjedalen, which are geographically located in the middle of Sweden. The area makes up just over fifteen percent of Sweden's area but is relatively sparsely populated with four percent of the country's inhabitants. The areal nutrients, especially forestry, still dominate, which characterizes the built environment. The Mid Sweden area was the leading region in Sweden and Europe in the early forest industry development at the end of the 19th century. A large proportion of the area still consists of forests and the forest industry is still a very important industry in the two regions. The buildings are concentrated in lanes along rivers, lakes and the Baltic Sea. The two largest cities are Sundsvall on the Baltic Sea coast and Östersund in the inland by the big lake Storsjön near the mountains. These two cities also constitute campus locations for Mid Sweden University.

Regarding the building culture in Mid Sweden, it is considered to be representative of Sweden as a whole and in many respects also representative from an international perspective. The three largest Swedish construction companies, Skanska, NCC and Peab, which have participated in the project, are also active in the international arena and apply largely the same concept and organizational principles in Sweden as internationally. Possibly it can be argued that the requirements for sustainability are particularly high in Sweden in comparison with other countries. This applies in particular to the work environment as Swedish work environment legislation places particularly high demands on health and safety and systematic work environment processes.

The SBEMS project was founded on the regional development strategies for the two regions Jämtland / Härjedalen and Västernorrland. These strategies emphasize the need for smart sustainable growth and that economic, ecological and social development should form the basis for the development of an attractive and sustainable built environment with regard to health and well-being in Mid Sweden. In order to build collaboration around these issues that are so important for the regions related to smart sustainable growth, the researchers at Mid Sweden University in the SBEMS project together with actors in the construction and real estate sector have identified and developed knowledge concerning issues with development potential and interconnection. Several municipalities and municipal real estate companies in the two regions have participated in the work of shaping and implementing the project. That also goes for companies in the construction and real estate sector.

1.2. Model for four sustainability dimensions

Sustainable construction is an overall term used to describe a building that is environmentally adapted in all respects. There is no clear internationally accepted definition of what is meant by the term, but Persson (2009) and Sutton (2020) has thoroughly analyzed and explained how sustainability can be defined [2–4]. When it comes to ecological as well as social sustainability, experience shows that it is often difficult to implement the initial ambitions in construction projects. This is due to lack of competence but also because sustainability criteria can be difficult to reconcile with short-term financial interests. One way to deal with this problem and at the same time increase competitiveness in the construction and real estate sector is to develop a model for sustainable building and planning through action research by including economic, ecological, social and cultural sustainability. Health and well-being are very important aspects of sustainable built environment. Special mention can be made here of the indoor environment where people spend over eighty percent of their time, and the work environment both during the construction process itself and in the work environments that are created in the built environment.

Compared with economic and ecological sustainability, social and cultural sustainability are relatively new phenomena in the construction and real estate sector. Admittedly, architecture, various functions and services in the local environment can be regarded as examples of social sustainability. Cultural sustainability means, among other things, learning from and relating to the traditional building culture with regard to construction and housing.

Figure 1 illustrates the model for four dimensions of sustainability. The dimensions should not be regarded in isolation from each other but as overlapping and interdependent.

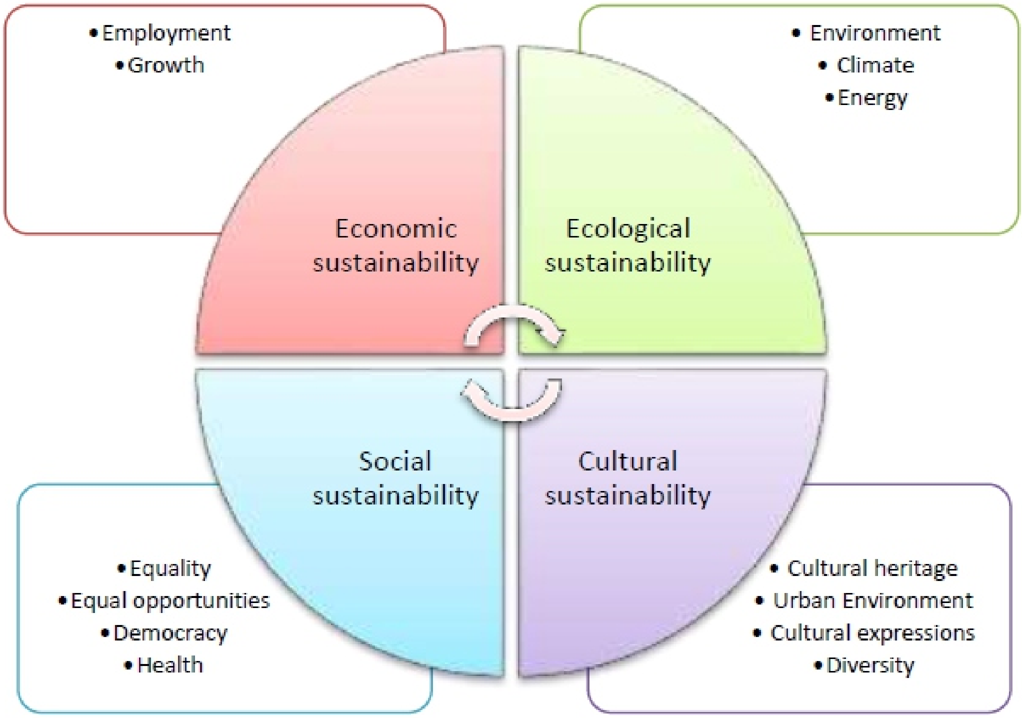

Figure 1. Model for four sustainability dimensions [1].

1.3. Model for sustainable building production

Work organization in the Swedish construction industry gives traditionally relatively good opportunities for workers to plan their own work. The self-governed team organization that is typical of the building industry is an example of an organic organizational model (Burns & Stalker, 1994; Mikaelsson, 1989), which has deep roots [5,6]. There are many experiences to get from that traditional model when forming a modern work organization with high degree of participation.

In the Swedish industry and the public sector, as consequence of the Codetermination Act, there has been developed forms of organization with a high degree of employee participation. The positive results achieved are improved safety, greater satisfaction and low absenteeism and high productivity [6,7].

In the years 1985–1988 the project "Integrated planning" was carried out by Lund University in cooperation with the building industry and the trade unions [8].

Integrated planning is based directly on the traditional organic team organization which traditionally have formed the work organization in the Swedish building and construction industry. However, this is not a sufficient condition for workers' experiences and views to be included in the planning. To enable this, the team organization must be integrated with the mechanistic construction project management organization [5,6].

Figure 2. Model for Sustainable Building Production (SBP) [9].

According to Mikaelsson & Larsson (2016), the IP model can be refined towards a Sustainable Building Production model (SBP). The refined model emphasizes developing understanding of four critical factors: strengthening leadership (especially healthy and effective, relation-oriented behaviors); increasing the focus on health and safety (work environment), especially worker selfestimates of health; basing a subjective quality perspective around modern quality management; and continually analyzing the impact of an organization upon its surrounding physical environment [9].

The starting point is the work environment on the construction site and how this can be improved with better production planning, work organization and leadership. The construction process is considered here in terms of sustainability with the aim to study how efficient construction with high quality can be combined with a good environment, health and safety. Important conditions to achieve this is a dialogue between the actors in the construction process in its various stages. The developer's wishes and expectations must be clearly spelled out in the program, drawings and descriptions as an adequate basis for the production. The schedule must be adapted to the available resources. This creates the conditions for a rational production with good work environment. The factors included in a sustainable building production model are usually being handled and integrated in Swedish building and construction companies in a concept called KMA (Kvalitets-, Miljö-, och Arbetsmiljöstyrning; Quality-, Environment-, and Work environment management) [9].

The aim of the SBEMS project was to study how sustainability factors can be implemented, developed and maintained with regard to initially set goals and actual outcome. Construction projects can generally be described as relatively linear processes where different actors act in different phases. The information about what is to be built must be transferred from one player to another over a limited period of time. These occasions where the information is transmitted can be termed critical borderlines. Construction processes are in fact very complex with many actors involved in different stages and this involves many critical borderlines where several and in some cases all actors are replaced. Important critical borderlines are from program to design then further to production when architects and designers hand over documents to building and construction companies and further to subcontractors who will carry out what the designers have described. Here, many good intentions and high ambitions when it comes to sustainability from the early program work risk being changed or lost. This can be bridged over by the bearers of the original visions participating in all stages of the process from the early idea and program stage to the finished building. To make this possible, the contractual legal aspects of the process must be taken into account. Communication and appropriate information systems are consistently critical factors. Errors and mistakes in the workplace can often be attributed to shortcomings in the information transfer. This applies to all levels according to Jonasson et.al. (2020) [10].

Sustainability adds even more complexity to a project, not least because the meaning of the word sustainability varies between different actors. New construction techniques or materials may be needed, as well as special expertise from other areas. When different actors negotiate with the goal of concluding an agreement, the ideal outcome is that the result is beneficial to all parties, even if the parties have partly conflicting interests. The result of a negotiation is usually a compromise, but even in projects that have a pronounced focus on sustainability. According to Svane et.al. (2011) the negotiations often lead to the environment getting the worst "deal" in favor of production economic factors [11]. It is therefore common that ambition levels of sustainability change between critical borderlines throughout the process so that initially high demands on sustainability are being changed in favor of traditional less sustainable solutions.

In the borderline between two stages in the construction process, the socio-technical system might be completely changed with communication and information problems as a result. This often happens between the program- and the production stage.

1.4. Purpose

The purpose of the SBEMS project was to actively and in collaboration with construction and real estate companies, users / residents and public organizations contribute to sustainable built environment in Mid Sweden by combining high demands on sustainability with efficient construction processes and collaboration between actors in the various stages of these processes. A specific purpose was to develop a general model for sustainable built environment based on ecological, economic, social and cultural dimensions [1].

2. METHODS

An action-oriented research approach has formed the basis for the entire project, where researchers and practitioners have collaborated within the framework of everyday activities. The researchers have contributed with scientifically based knowledge and expertise on issues of economic, ecological, social and cultural sustainability. The principle test-feedback-development creates open systems for knowledge production in collaboration with practitioners, which provides conditions for robust knowledge. Collaboration between different actors in the business community is often a prerequisite for innovative solutions, but equally important for this project is that municipalities and municipal real estate companies have been involved in the planning and implementation of the project.

This applies to Sundsvall municipality (and the real estate company Mitthem), Östersund municipality (and the real estate company Östersundshem) and Ånge municipality (and the real estate company ÅFA). Via the industry council for Sustainable Construction at Mid Sweden University, there has been an established collaboration platform between the university and the construction industry and the municipalities for many years. This industry council has been the reference group for the project. The research has to a large extent been linked to case studies of a number of building and construction projects with the ambition of covering different stages of relevant construction and housing processes [1].

As the Storsjö Strand project had high ambitions regarding sustainability in the initial phases it was a particularly interesting project for a case study in order to study goal fulfillment from program to production [1].

Supplementary studies of other construction projects have been carried out in order to study the implementation process. Special mention can be made here of the project Grönt Boende (detached single-family house in Sundsvall), the Hallstaborg project (rebuilding of a retirement home in Ånge municipality) and Remonthagen (rental housing in Östersund). Studies of sustainability processes have also been carried out in collaboration with the large national construction companies, NCC, Skanska, Peab and some smaller local construction companies. Studies of routines and activities related to the project's purpose and goals in these companies are included as an important part of the research project.

The methods has been interviews with key actors, participation in planning meetings, study visits with own observations and studies of planning documents and other written documents. The research questions have been focused on communication and information problems that arise between the program and design phase and from design to the production phase and how these problems can be addressed with the help of integrated planning and better continuity in the construction process. The overall question is how the original visions of sustainability are processed through all stages from the early idea and program stage to the finished building [1].

3. RESULTS

3.1. Bridging critical borderlines from program- to production stage

The critical borderline between program- and production stage has been studied in the case Storsjö Strand, a housing project in the center of Östersund by the big lake Storsjön. The goal for the area is to be an attractive and accessible addition to the city center with the following plans in terms of sustainability for the district formulated by the planning office: "The district will be supplied by renewable energy sources and show the way to future climate-smart buildings where a life cycle perspective is in focus " [12].

In the evaluation of how Östersund municipality's sustainability program turned out for the first stage of the Storsjö Strand project, the affected developers and administrators at Östersund municipality were interviewed. Initially, it was investigated how the sustainability program and the sustainability goals, and even the intentions behind these programs and goals were transferred across the critical borderline between developer and contractors. In order to meet the municipality's high ambitions regarding sustainability for the area, a design program for the entire area and an ecological sustainability program for the first stage were prepared. The design program was a common guideline for the municipality and the developers regarding design, construction, production and facility management of the buildings within the new district. The sustainability program describes how the work from the idea stage to facility management should be in order to fulfill sustainability requirements [12].

The studies of sustainability programs and life cycle analyzes showed that actors with practical building technical knowledge should have been involved early in the process. Experience from other project shows that such integrated planning creates not only higher sustainability but also a more costeffective construction process with less conflicts and less problems later in the process as it provides conditions for not having to make changes and additional work during the project. The sustainability program has nevertheless permeated the entire process. The builders have been aware of the content of the documents and worked to meet the goals as much as possible. With revised and measurable goals, the sustainability program could be improved for future stages of the Storsjö Strand area. In order for sustainability programs to be fully implemented and the original intentions to be maintained, the construction contractors should be involved at an early stage in the project, in order to increase their own competence but also to contribute knowledge [12].

In the master plan of Sundsvall and in the sustainable one the growth strategy highlights the need for attractive and varied accommodation with sustainable technical systems. Because of it - and an idea from architect Anders Nyquist to build villas in Sundsvall with the best available environmental technology - Sundsvall municipality created the project Green living (Grönt boende) in the years 2014–2016 [13].

To find families who wanted to build a new house in an environmentally friendly way the municipality, together with Mid Sweden University, created a series of seminars held during the period February-May 2015. It contained five seminars construction technology, construction economics, the construction process and sustainable lifestyle. The purpose of the seminar series was to give families knowledge in planning and carry out the construction process on a sustainable way. The evaluation showed that the families increased their knowledge using the seminar series. Based on the seminar series, the families received information, inspiration, ideas and new knowledge to build their houses.

The families had deepened their current knowledge through materials provided by the project and by themselves actively sought additional information online. With the received knowledge the four families created their own environmental program and described in which way they wanted to build their house [14].

3.2. Sustainable building production

As a complementary study two construction processes have been followed in order to further develop and test the model Sustainable building production (SBP) according to figure 2. [9].

A special study has analyzed how the work environment plan can form the basis for such a process. The processes were followed up by the researchers through parts of the design phase and the entire production phase until completion.

One case study was the Hallstaborg project, a rebuilding of an elderly care center in Ånge municipality. The commissioner was the municipality facility company (ÅFA) which is also was the building contractor. The starting point for the project was the work environment plan. It was set up by the architect in dialog with the site manager and the safety delegate. The site manager, who also was the work environment coordinator, set up lay out plan, time schedule and the other production plans with regards to the work environment plan. The current planning process during the construction phase was coordinated by the site manager in dialog with the safety delegate and by regular planning meeting once a month with all subcontractors and working teams. The planning meetings was an arena for current steering and coordination of the building process and building production. The planning process was carried through from a holistic perspective with integrated work environment-, quality-, environment management which requires a transformative leadership [9,15].

The Hallstaborg project in Ånge municipality is a good example of a rebuilding project implemented with a variant of sustainable building production with the work environment plan as the governing document. A work environment plan (AMP) for the entire construction process must be drawn up for each construction project in accordance with Swedish work environment legislation. In the Hallstaborg project AMP was used as a governing document for planning according to the SBP model. That illustrates that AMP is not only a statutory planning instrument for a building and construction projects. It can also be the starting point for SBP [9,15].

Another example is the Remonthagen project in Östersund. It was the building of seven multistore houses just outside the center of Östersund with Skanska as the main contractor.

Skanska has a general policy for work environment with a high-profile concerning health and safety. In the Remonthagen project there was a special focus on work preparations, a joint detail planning for building components or elements, in order to reduce incidents and accidents. The supervisor together with the workers made the planning that took advantage of the employees' skills and that made decisions firmly established in the whole group. Work preparations had the starting point in health, safety and work environment and it also provided an open and good working climate. Also, quality and other sustainability factors were regarded in the process [16].

At the Remonthagen project the aim was to surpass the general work environment policy for Skanska and the project have got an internal price for the best work environment in the region. The motivation was the active cooperation with all employers and work teams and the efforts for high degree of participation and awareness in the systematic work environment realization. Some success factors that were specially important were regular planning meetings for all employers with strong work environment focus where quality-, environmental-, and other important production matters were integrated [16].

The starting point for the planning process was the work environment plan according to the provisions [17,18]. The current systematic work environment realization at the site followed the descriptive diagram for systematic work environment management, and the production planning followed the principles of integrated planning (Figure 2) [16].

In both mentioned cases the planning process started with the work environment plan according to the provisions [15–20]. The current planning process to a certain extent follows the principles of integrated planning according to the SBP model (Figure 2) [10,15–20]. The two case studies in practice illustrate a concept for Integrated Work Environment Planning (IWEP). The results indicate that the work environment plan according to the provisions can be the starting point for implementing the concept SBP [15–20].

Studies of Skanska, Peab, NCC and other construction companies show that SBP is a model for continuous feedback of experience that can be rather easily implemented and function in practice. It is thus possible to implement SBP at an early stage with the help of the AMP. SBP is also a concept for coordination and communication of activities in a construction project. It is an informal model that can be applied more or less in all forms of procurement (partnering, own management, shared contract, general contract and turnkey contract). All actors in the process participate by virtue of their regular roles (users, clients, planners, site managers, supervisors, team bosses, contracting engineers, subcontractors and safety representatives). It is of course up to the developer to decide if and how the model is implemented in each project. The researchers' task here has been to present a proposal for a working model and to follow the process in all its stages with an action research approach [1].

SBP means planning with a high degree of involvement of the actors involved in situations characterized by variability and high demands on sustainability. Briefly, model can described as follows. At the center of the model is in each construction project a planning group of formal leaders and representatives of the working teams and working groups. This planning group makes a proposal for planning which is discussed and agreed upon at a start-up meeting with all concerned. Throughout the process, a dialogue takes place between the planning group and the work team for continuous reconciliation and rolling planning. The socio-technical system that changes during the process can be handled in this way despite the fact that new actors and working groups are introduced while others leave the project. That means that the critical boarderlines in the production stage can be bridged.

3.4. Knowledge generation and exchange of experience

This sub-project Knowledge generation and exchange of experience has run in parallel with other sub-projects in the SBEM project with the ambition of connecting these through dialogue seminars and sustainability summits for knowledge generation and exchange of experience in sustainable built environment. On these occasions, researchers, primary and secondary stakeholders have participated.

All stakeholders have been given access to current results and have been able to discuss these before the results are presented publicly. In addition to these special events this subproject has worked to raise debate about the areas of conflict that arise at the intersection of different sustainability dimensions and more general dissemination of information about the SBEMS project in the form of reports, articles, books, cell films and podcasts. In total, two anthologies, two reports, two articles and five podcasts has been produced. Each of the two anthologies consists of chapters written by researchers from the SBEM project, researchers from other universities and practitioners. The two articles have been presented at international scientific conferences. The five podcasts have been downloaded around 400 times each, which according to Mid Sweden University's communication department is a good number of listens compared to other similar podcasts at the university. Both researchers and practical professionals who have in some way been linked to the SBEMS project have contributed to disseminating results and information about the work that has been passed on to others. Furthermore, participants in the project have been part of the group that has built up a sustainability network at Mid Sweden University.

The purpose of the dialogue seminars in the SBEMS project was to spread knowledge from the project to a wider target group and initiate discussions about this. The seminars have also made it possible for new development projects and further development of projects that already were initiated.

The dialogue seminars have started a long-term sustainable collaboration between various citizen groups, property owners and other private actors as well as public projects and institutions. The process has contributed to the joint design of visions and goals for urban development. The participants themselves proposed activities and organized themselves into different groupings to work with the implementation. The work has been carried out between the dialogue seminars and is reported at the seminars when new goals could be launched and new groups formed. This approach has been well received and is still continuing after the end of the project period.

4. DISCUSSION

One of the goals of the project was to develop a model for sustainable built environment based on economic, ecological, social and cultural sustainability dimensions. In reality the economic dimension tended to grow larger than the other three dimensions quite early in the surveyed construction projects in order to expand further over time at the expense of the other dimensions. The reasons for that are:

External factors such as regulation can cause problems. These factors cannot be controlled by construction and real estate companies and affect the possibilities of acting from an ideal model.

Overoptimistic calculation and initially high ambitions are often stated in order to get permission to start construction projects at all. This means that renegotiations may need to be made later in the process and that ecological, social and cultural sustainability dimensions may be downgraded.

Time pressure means that projects are forced and sustainability efforts are downgraded. There are industry-specific obstacles and cultural traditions in the construction and real estate sector that counteract multidimensional sustainable development.

A procurement where the contractor who has submitted the lowest price gets the job, may mean that there is less room for financial flexibility. This can lead to sustainability efforts are being downgraded for financial reasons.

The research group has also identified several development areas as follows:

Incentives are needed to stimulate new thinking in the construction and real estate industry before an ideal model can be introduced.

Cooperation between municipalities, construction and real estate companies and other actors is needed to establish a holistic approach to various sustainability dimensions. The developer competence needs to be strengthened, especially with regard to sustainability aspects but also with regard to production economics aspects. Alternative financing solutions need to be developed. Business economics calculations need to be supplemented with socio-economic calculations. In connection with this, the business economic time horizon needs to be more long-term. In summary, it can be stated that in the high-ambition projects examined, one or more sustainability dimensions might collide and that the economic dimension then tends to become controlling. This could indicate that it can be difficult to develop a balanced model for sustainable building and construction processes based on economic, ecological, social and cultural dimensions.

This indicates that a model for sustainable built environment based on these dimensions needs to be supplemented with methods for overcoming critical borderlines.

5. CONCLUSIONS

Although there are many obstacles to formulate a general model for sustainable built environment, the results from the project SBEMS provide indications that a combination of different initiatives and models can be fruitful. The model for four sustainability dimensions according to figure 1 can advantageously be introduced very early in the process in the form of open dialogue seminars. It can advantageously be combined with the model for sustainable building production according to figure 2 already in the idea and program phase and then move on through all stages of the project.

6. Further research and development

A pilot study is underway in collaboration between Mid Sweden University and Jamtli, a regional museum for sustainable built environment, and other actors with ambitions to develop an arena for the sustainable built environment. The project is called Jamtli Living University (JLU) and the models from the SBEMS project will be implemented and tested in full scale building projects.

Through dialogue seminars a network is established between regional and national social stakeholders; academia, business, the cultural sector and the public. The device for the project is development of built environment from past to future. The JLU network is a tool for sustainable development that combines the best from traditional construction and housing with the sustainable built environment of the future.

Conflict of interest

The authors declare no conflict of interest.

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Hydrogeochemical Assessment of Mine Water Discharges from Mining Activity. Case of the Haut Beht Mine (Central Morocco)

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ABSTRACT

The rocks are likely to give a geochemical signature to the groundwater circulating there. Therefore the hydro geochemistry of the mine's water is influenced by the mining method. The continuous pumping of the mine water gives discharges that induce harmful impacts on the environment. The Sebou basin is subjected to strong industrial and urban pollution, but in the literature, the evaluation of the mining impact on this area is neglected. This paper is dedicated to this issue and as part of the evaluation of the mining impact on the Sebou watershed, the haut Beht mine was chosen among the four mines which include the watershed, and then we proceeded, as the purpose of this work, to evaluate the physicochemical quality of this mine's water discharges and their metallic trace elements (MTE) load (As, Pb, Cd, Zn, and Cu) through monitoring of four locations during two analysis campaigns in 2014 and 2015. This monitoring was performed by ICP-MS analysis. The results showed absenteeism of the acidic nature of mine's water, characterizing acid mine drainage (AMD). The majority of the analyzed water presents important concentrations of sulfate. During the 2014 campaign, the examination of trace metal element concentrations showed, at station 2, contamination of Iron, Aluminum, Manganese and, Arsenic. However, the concentrations of Pb, Cd, Zn, and Cu elements remain conform and very low compared to the limit of standards. The monitoring of the overtake elements made it possible to identify the degree of contamination of the mine's water discharges and to note an improvement in time in the mine water discharges quality.

Keywords: Sebou River; Environment; metallic trace elements; mine water; discharges

1. INTRODUCTION

The interest of evaluating the impacts of mining and its wastes on the environment did not arise until the 1990s. This interest required, in several countries, the implementation of mining activities regulations to limit the risks of pollution and to preserve natural ecosystems. Like in other countries, the mining sector in Morocco has found itself confronted with this environmental issue. The mining regulations (law 33-13) aim to set a range of new conditions for mining, taking into account the environment parameter during all phases of exploitation and post-mine. However, the problem of old mines exploited and abandoned without rehabilitation still remains [1,2].

Mining generates negative impacts on the environment as a result of direct or indirect effects during activities and/or after the closure of the mine [3,4]. Freshwater basins are the most affected element by such activities due to the water usage for the ore treatment and mine water discharges [4].

Thus, mines are increasingly threatening the water resources on which the whole ecosystem depends. Water is then considered as a "victim of mining" [5]. Metals are omnipresent in surface and ground waters, and their concentrations are generally very low, hence comes the name "metallic trace elements (MTE)". Mineral deposits are concentrations of metallic or other mineral commodities in the Earth's crust that result from a variety of complex geologic processes. The natural weathering and erosion of a mineral deposit at the Earth's surface disperse their constituents into the waters, soils, and sediments of the surrounding environment [6,7]. Thereby, the exploitation of a deposit rich in metals generates a change in terms of the quality of the water in contact with the mining works [8].

Around the world, several previous studies have been devoted to the problem of the abandoned mines' impact on the environment [2,9–17]

The present work falls within the general perspective of understanding the pollutants behavior and the metallic trace elements mobility in the mining environment, through the diagnosis of the current contamination situation and its evolution over time. The aim of the work is to ensure the protection of the environment against the nuisance caused by mining activity in the study area. The haut Beht mine is located at the Beht watershed which is part of the Sebou watershed (sub-basin) (Figure 1). The Sebou River drains one of the main watersheds of Morocco in terms of water resources. However, it is subjected to a strong pollution [18–21]. The waters of Sebou have been experiencing a significant deterioration in their quality for several years, due to domestic and industrial discharges [22–25]. The Sebou watershed contains 13.3% of the country's industrial units, 7% of which are located in the Fez region, 3.2% in the Meknes region, and 3.1% in the Kenitra region [18]. In several previous studies, water pollution in the sebou basin and its sub-basin Beht has been treated, among these studies we can cite [18–24]. for the Sebou and [25–28]. for The Beht, but to our knowledge there is no study that has been dedicated to the evaluation of the mine water discharges quality and their impact on the environment like this work.

The purpose of this work is to evaluate the physicochemical quality of the Haut Beht mine water discharges and their metallic trace elements (MTE) load (As, Pb, Cd, Zn, and Cu) through monitoring of four stations during two analysis campaigns in 2014 and 2015. The mine water which is considered in other studies as natural mine discharges, because when the continuous pumping of the water from the mine stop in the abandoned mines, its mine water infiltrates and becomes more charged in the mine, achieving by gravity the underground waters and contaminating it by heavy metals. The mine water discharges are originally from the mine, and they are different from those coming from the mine tailing dam which is treated in several studies as the only mine' discharge. The evaluation of the mine water load in trace metal element and other analyses in this work are elaborated in the world for cases of sustainable management of mine water discharges and the reduction of their environmental impacts, or in the context of the performance monitoring of a treatment station of mine water discharges, or for post-mine monitoring and impact assessment (Table2).

2. MATERIALS AND METHOD

2.1. Presentation of the study area

2.1.1. Geographic and hydrological context

The study area is in the Beht watershed (sub–basin of the sebou watershed: The watershed of the river Beht is located northwest of Morocco and occupies the southwestern part of the Sebou basin), which is bounded on the north by the Gharb plain and the Meknes plateau, on the south by the Oum-Erbia basin, on the west by the Bouregreg watershed and on the east by the Middle Atlas, which occupies the southwestern part of the Sebou watershed in northwestern Morocco [29]. The administrative territory of the Beht watershed overlaps contains five provinces and twenty-six Rural Communes (Figure 1). The study area has a mountain character, and does not contain a generalized groundwater table. The water resources of the localized water tables are used in the form of springs or by wells in the alluvium by the local populations for the irrigation of small plots or the supply of drinking water. In addition, there are alluvial aquifers along the Beht river where small perched aquifers with low flow rates are found. The HBM mine is located on the boundary of Beht river, The main affluent of the Sebou river, and its two affluents 1 and 2 (Figures 1 and 3). The Sebou watershed covers an area of 40,000 km2 located between the meridians 3°50' and 6°40' W and the parallels 33°and 35° N. This watershed, which includes 1/3 of Morocco's surface water resources, is drained by the Sebou river that originates in the Middle Atlas and travels about 500 km before reaching the Atlantic Ocean near Kenitra [30]. The watershed of Sebou is the richest in terms of water resources in Morocco, with water supplies of the basin amounting to more than 5 billion m3/year, and it is one of the regions with the most important potential of irrigable and irrigated lands and industries at the national level. All these activities affect the quality of waters in this basin and cause more or less significant changes to the living communities [22,24,31].

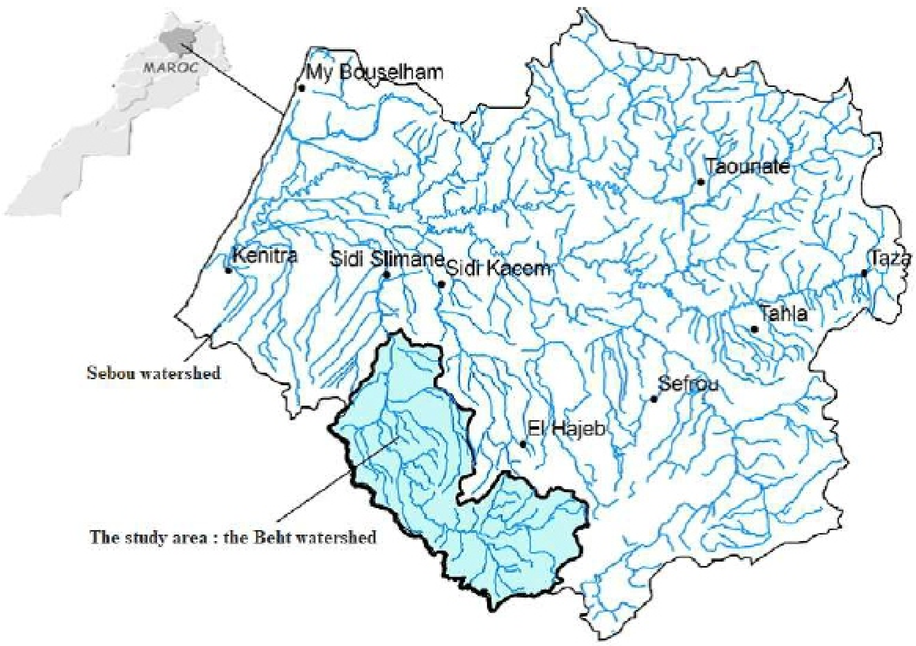

Figure 1. Geographical location of the study area: the Beht watershed in the context of the Sebou watershed [25].

2.1.2. Geological and hydrogeological context

From a geological point of view, the mine studied is located in the north-eastern part of the massif of central Morocco, which is a northern zone of the western Meseta [32,33]. This zone consists essentially of a Neoproterozoic substratum (acid or intermediate lava and low flush granites) [34,35], a Paleozoic cover (Cambrian to Permian age) and sedimentary and volcanic Meso-Cenozoic cover [2,32,33,35,36]. The main Paleozoic formations of the mine are: micro-conglomeratic schist, Ordovician quartzite (Ashgill), and Black Silurian graptolite shale (Gothlandian) [37,38]; yellow tentaculite schist is associated with sandstone banks and Devonian seedy limestone formations [38] (Figure 2). The mine is located in a dislocation zone of the Smaala-Oulmes (NE-SW) major fault, which ends at the NE with several branches of the same direction and shows NNE-SSW branches [38–41]. The system of this fault is truncated further to the north by the Tafoudeit accident overlapping the Namur formations and the Visean lands [37,38,42].

The mineralogical study in different areas of the massif of central Morocco made it possible to distinguish different types of ores, as breccia pyrite brecciated ore, massive ore with pyrrhotite, pyrite milky ore, and ribbon ore with pyrrhotite and chalcopyrite. The mineral paragenesis is dominated in some areas by pyrrhotite (more than 90%) with pyrite, chalcopyrite, magnetite, and glaucodot (Co, Fe) which are all associated. On the other hand, sphalerite, galena, and arsenopyrite are present in accessory quantities [43–48]. The regional geological framework has given mineral richness to the Sebou watershed, which includes four deposits (active and abandoned) [2,49,50].

The study area does not contain a generalized groundwater table. The water resources of the localized water tables are used in the form of springs or by wells in the alluvium by the local populations for the irrigation of small plots or the supply of drinking water. In addition, there are alluvial aquifers along the Beht river where small perched aquifers with low flow rates are found.

Taking into account the predominance of schistose and marl formations that form the watershed of the Beht river, it seems certain that the Groundwater availability in the Beht Basin remains very low. The existence of some auriferous rocks, with low water productivity and very limited extension, is mainly related to secondary modifications affecting the initially impermeable formations, to which are added appropriate structural forms (faults) [51].

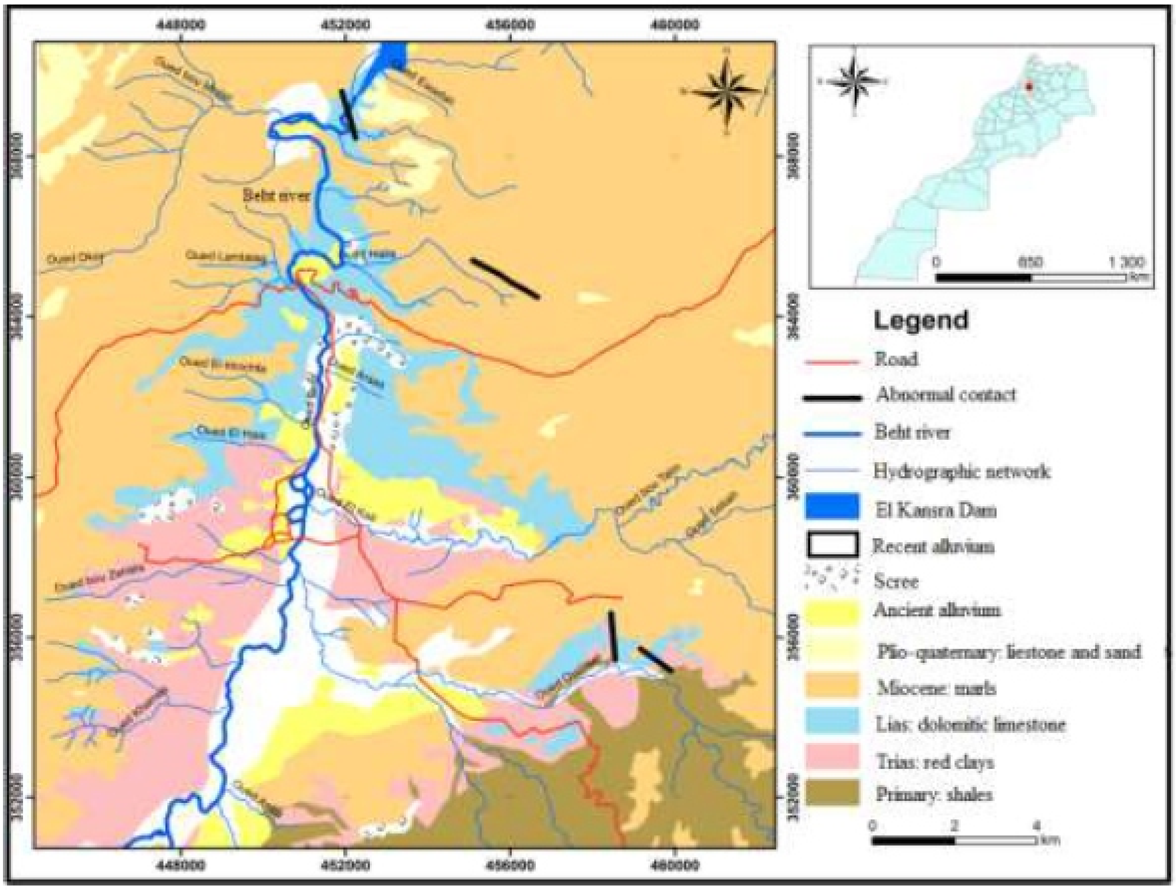

Figure 2. Geological map and structural domain of the Moroccan Hercynian central massif [52].

2.1.3. Climatic context

From a climatic point of view, the mine is located in the Beht watershed, the region's climate is a Mediterranean type with oceanic influence and becomes continental inland [25]. It is manifestedby rainy winds coming from the west and decreases in precipitation away from the sea and in protected valleys like those of Beht or high Sebou before increasing rapidly on the slopes of the Rif. These influences of altitude, latitude, and exposure are combined to form a local microclimate where cold, frost, snow, and winter rains can oppose summer heat and thunderstorms [53,54]. The rains are poorly distributed throughout the year and very irregular from one year to the next. Average annual temperatures in the watershed range between 15 °C and 19 °C depending on altitude and continentality summer temperatures are high, the hottest months are July and August with average highs of 34 to 36 °C and the coldest months are December, January and February. The average of the minima is 3 to 7 °C [29]. The annual average rainfall in the basin is 600 mm on average with a maximum of 1000 mm on the heights further northward and a minimum of 300 mm [53].

2.1.4. Soil type

The soil cover of the Beht watershed is essentially characterized by soils whose chemistry is dominated by the presence of varying amount of alkaline earth (calcium and magnesium) because of the limestone backbone of the area [55]. The lands of the Beht watershed are limestone clay-loam in nature, the upper horizons of which are relatively rich of organic matter. They are formed on the recent and sub-current alluvial deposits of the Beht river. The porosity is medium, and the compactness is quite high. Structural stability of water is precarious, and under the effect of excess water (irrigation, rain), the upper horizons become crusty (beating soil) [56].

2.2. Sampling stations

In the context of the study of the impact of mining activity on the environment at the Sebou watershed that we chose the haut beht mine (HBM) among the four (active and abandoned) mines that include the Sebou watershed [2,49,50], and we proceeded to a physico-chemical characterization of its mine's water discharges and an assessment of their load in metallic trace elements and their potential and punctual impact on the environment, through two sampling and analysis campaigns, in 2014 and 2015 at the four discharge points of the mine's water.

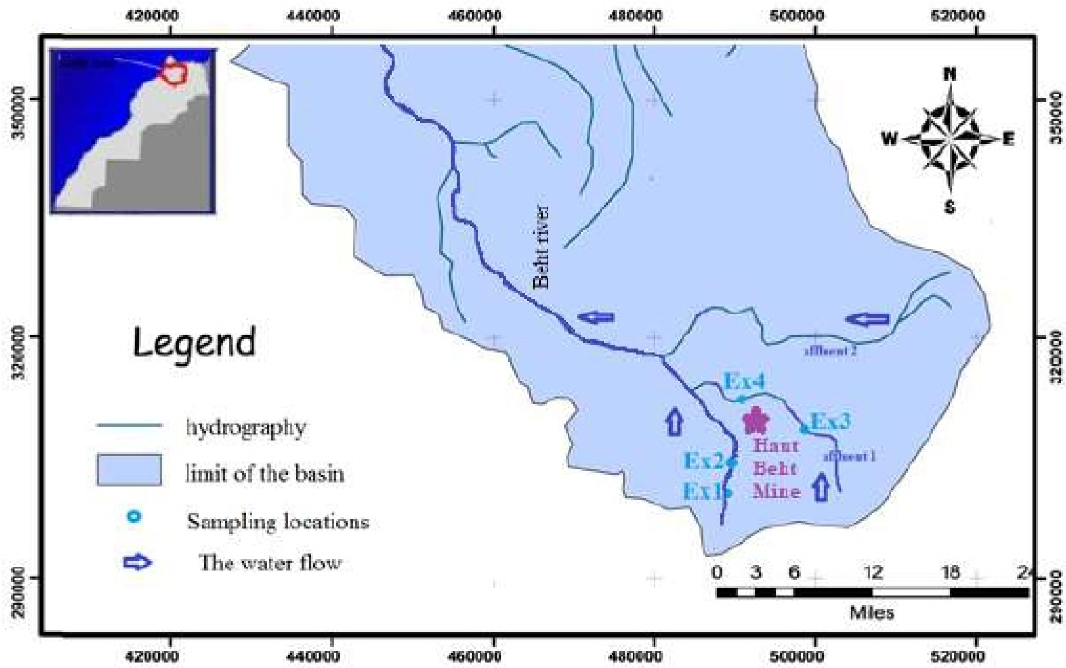

Figure 3. Map of the location of the study area and the four sampling stations.

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The sampling stations were chosen to assess the physico-chemical quality and the trace metal load of the mine's water discharges. At the four selected stations, four water discharge samples were taken during two sampling and analysis campaigns carried out in 2014 and 2015 (Figure 3).

- **Station 1: (Ex 1):** the water discharge of the station 1 is located upstream of all other discharge points on the Beht river.

- **Station 2: (Ex2):** the water discharge of the station 2 is located downstream the station 1 (Ex1) on the Beht river.

- **Station 3: (Ex3):** the water discharge of the station 3 is located upstream of the discharge point of Ex4 on the same affluent of the Beht river, affluent 1.

- **Station 4: (Ex4):** the water discharge of the station 3 is located downstream the discharge point of Ex3 on the same affluent of the Beht river affluent 1.

2.3. Methods of analysis

The mine water discharges samples were taken in 2014 and 2015 at the four sampling stations. Sterilized polyethylene vials were used for sampling, and each sample was taken to avoid the degassing of the sample, then to do this each bottle is filled gently while minimizing the effects of turbulence. Hermetically sealed, sample vials are stored at 4 ° C for rapid transport to the analytical laboratory in order to avoid changes in chemical composition due to degassing and photo-lytic or microbial reactions. Water discharges samples were acidified by the addition of 4% nitric acid to avoid changes in MTE concentration.

Following standardized methods (Table 1), 19 variables were monitored physico-chemically, including two in situ (pH, temperature).

The heavy metal analyzes were performed by ICP-MS (inductively coupled plasma mass spectrometry), which is a highly sensitive technique with detection limits up to part per trillion (ppt) (ng / l), for monitoring the evolution of the metal charge of water discharges in five particular elements: Lead (Pb), Zinc (Zn), Copper (Cu), Cadmium (Cd) and Arsenic (As).

The two sampling and analysis campaigns of water discharges (C1: 2014 campaign and C2: 2015 campaign) were carried out by a state-approved laboratory. The samples were taken following the AFNOR standard NF EN 25667 (ISO 5667) (table 1). Table 1. The references of the basic analytical methods adopted by the analytical laboratory.

TESTS	REFERENCE METHODS	TESTS	REFERENCE METHODS
Accredited tests in chemistry	Accredited tests in chemistry		
pH	NF T 90-008 / NMISO10523	As	FD T 90-119
T °C	NF EN 25667 (ISO 5667) /NM 03.7.008	As	NF EN ISO 11885
Sulfates	NF T 90-040 / NM ISO 9280	Al	NF EN ISO 11885
Pb	FD T 90-112	Al	FD T 90-119
Pb	FD T 90-119	Zn	FD T 90-112
Pb	NF EN ISO 11885	Zn	NF EN ISO 11885
Cd	NFENISO5961	Cu	FD T 90-112
Cd	NF EN ISO 11885	Cu	NF EN ISO 11885
Fe	FD T 90-112	Cr	NF EN1233
Fe	NF EN ISO 11885	Cr	NF EN ISO 11885
Mn	NF EN ISO 11885	Sb	NF EN ISO 11885
Mn	FD T 90-112	Ni	FD T 90-119
Co	NM 03-7-022	Ni	NF EN ISO 11885
Co	NF EN ISO 11885	Se	NF EN ISO 11885
Sn	NF EN ISO 11885	Se	Se FD T 90-119
Ag	NF EN ISO 11885		

3. RESULTS AND DISCUSSION

3.1. Physicochemical characterization and metallic load of the mine water discharges

The exploitation of deposits rich in sulfides [43–46,57] expose rocks to the action of air and water which together have a strong oxidizing power. Oxidation of pyrite, and other associated primary minerals in sulfide deposits, results in mine water characterized by significant amounts of sulfates and dissolved heavy metals. [58]. The heavy metals chosen in this study are linked to sulfides because the arsenopyrite is the main source of arsenic (As), the Chalcopyrite contains most of the copper, the Zn and Cd are in sphalerite [8,59], and since the native lead (Pb) is rare, and due to its chalcophile nature, it is associated with sulfide deposits [8,47,48].

All of the analysis' results of the eight samples of the mine water discharges collected during the 2014 and 2015 campaigns were compared with the general limit values for discharges into surface or underground water. The analysis of the results obtained made it possible to identify the pH variability, which is a feature key of acid mine drainage (AMD), as well as the elements in excess and the elements relating to the metallic load of water discharges, in particular lead (Pb); Zinc (Zn); Copper (Cu); Cadmium (Cd) and Arsenic (As).

3.1.1. pH

The pH varies between 7.6 and 8.35 during C1 and between 7.6 and 8.2 during C2 (Figure 4). The upstream/downstream spatial distribution of the sampling stations shows a low variability of the pH values recorded during the C1 and C2 campaigns.

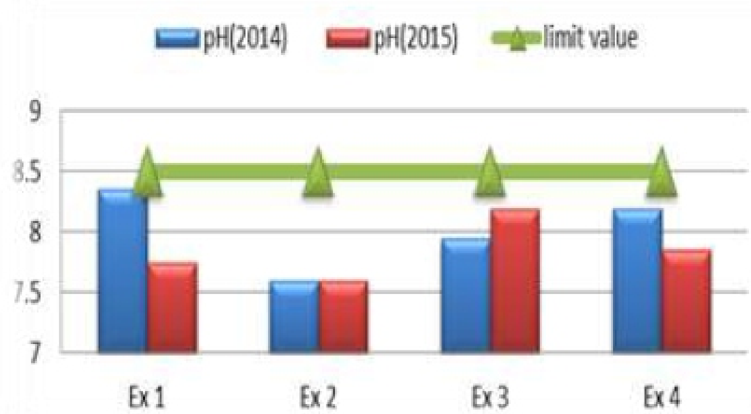

Figure 4. Evolution of the mine water discharges pH during the C1 and C2 campaigns.

The mine water discharges have a neutral to slightly alkaline pH (7< pH <8.5), which indicates an absence of the acid character of the mine water, which is the main character of acid mine drainage (AMD) [60], in all the samples analyzed in C1 and C2. The variation in the pH contents of the mine water discharges between C1 and C2 is linked to several factors, including the depth of the mine, because as the water circulates deeper in the mine, its overall mineralization increases due to the geochemical background changes resulting from the advancement of mining operations. As well as the residence time of mine water in the mine and the contact time of mine water with the rocks (leaching of the bottom walls) because when the transit time of this water is sufficient, it occurs exchange of bases between the cations of the clays from the bottom of the mine and the cations contained in the water, which causes further changes in pH concentrations [61]. This seasonal variation in the mine water pH concentration can also be related to the rainfall conditions of the sampling period, because during a heavy rainy event the mine water records a supply of meteoric origin water. This water is very weakly mineralized with a rather acidic tendency (pH of rainwater between 6 and 6.5), which causes the drop of the mine water pH concentrations [62].

This neutral to basic character of the mine water can be explained by the fact that the AMD phenomenon is not encountered in all sulfide mineral mining operations, especially when mineral phases in the bedrock are able to neutralize the acidity produced [45,57]. With the presence of carbonate, the acidity produced is neutralized by the dissolution of carbonates witch greatly slow the solubilization rate of contaminating metallic trace elements. It is a neutral mining drainage (NMD) [63]. The capacity of the sulfides to produce acid is determined by the relative content of the acid-generating mineral phases and the acid-consuming phases; if the acid consuming such as calcite and bauxite are present, the resulting water can be neutral pH containing high concentrations of sulfate and metals [64]. In the geological context of the studied area, the presence of carbonate minerals such as calcite, promotes a natural neutralization in situ of the acidity of the mine water discharges by producing a NMD [65,66].

3.1.2. SULFATE

The sulfate contents vary during the C1 between 131 mg/L recorded at the station Ex 3, and 1413 mg/L recorded at the station Ex 4, and between 131 mg/L at the station Ex 1 and 1310 mg/L at the Ex 4 station during the C2 (Figure 5). The station Ex3 shows the two lowest sulfate concentrations noted in both C1 and C2 campaigns with a slight increase in C2. However, the station Ex 4 shows the two highest sulfate concentrations recorded during both C1 and C2 campaigns, with a significant decrease in C2.

All sulfate concentrations recorded at the mine water discharges during the C2 are lower than those recorded during the C1, except on the station Ex 3. The sulfate values recorded at the totality of the mine water discharges sampling stations exceed the limit value of the industrial discharges set at 500 mg/L, except on the station Ex 3, which represents lower concentration to the standards during the two analysis campaigns (Figure 5).

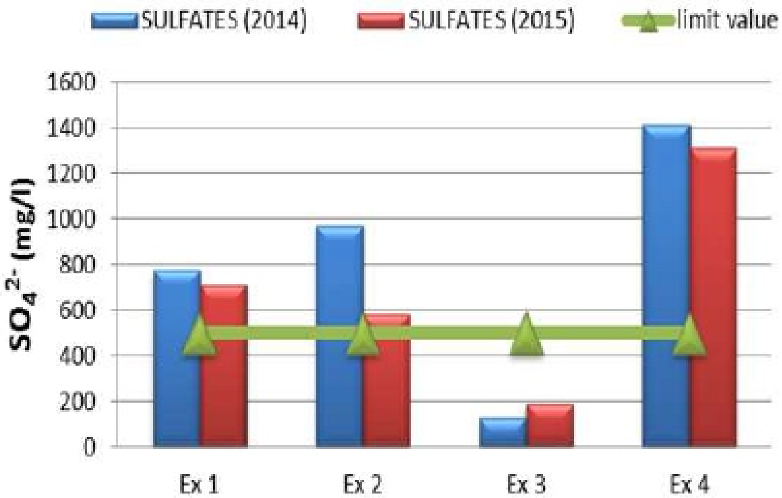

Figure 5. Evolution of sulfate content of the mine water discharges during the C1 and C2 campaigns.

The high concentration of sulfate in the mine water discharges is mainly related to the exploitation of sulfide ore [66] due to the oxidation of the mineral sulfides by producing heavy metals and sulfate [67].

The variation in the sulfate contents between C1 and C2 at the Ex1 and Ex2 stations is linked to the progress of the underground mining works, because the geochemical background changes and induces the modification of the mineralization of the mine water discharges. The increase of the depth of the exploited levels induces the decrease of the sulfate contents because the high sulfate contents characterize the water circulating through shallow mining works [61,68–70]. The factor of the contact time of the mine water discharges with sulfide rocks at the mine (residence time in the mine) can also be a determining factor for the sulfate concentrations in the mine water discharges, because sulfates come from the oxidation of pyrites at the contact of water and air [61,71].

Furthermore, the sulfate concentration recorded in the station Ex 3, which does not exceed the industrial waste limit values during the C1 and C2 analysis campaigns, is probably related to the dilution phenomenon, since the final discharges sampled in this station are composed of the mixture of mine water used for mining and a large part of the dewatering of the deposit which has a significant water wealth. The discharges rate at this station accounts for more than the half of the mine's water discharges.

3.1.3. ALUMINUM

Aluminum concentrations show a very low variation during the C2. However, during the C1, the values recorded at the four measurement stations are less than 1.5 mg/L, except on the station Ex 2, which has a value of 14.1 mg/L, which exceed the limit value of the industrial discharges in the surface and underground waters setting the threshold value at 10 mg/L (Figure 6).

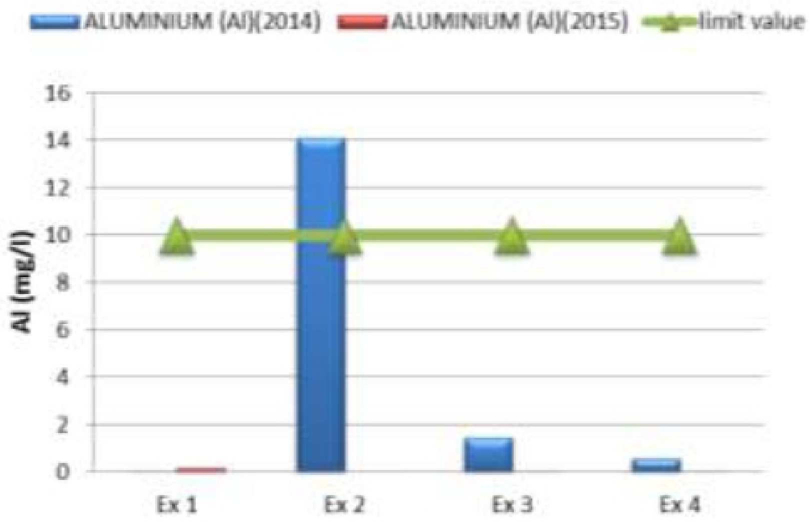

Figure 6. Evolution of the aluminum content of the mine water discharges during the C1 and C2 campaigns.

Aluminum is the second most abundant metal in the earth after iron [72]. The origin of aluminum in the mine water discharges can be linked to the geochemical alteration of rocks in contact with water and oxygen during mining it corresponds to total hydrolysis, which results in the release and drainage-driven elimination of minerals constituents. It should be noted that iron and aluminum oxyhydroxides are insolubilized. This alteration leads to the formation of newly formed clays, which can induce an increase in the turbidity of the mine water discharges circulating through the mine. Thus, the turbidity of the mine water discharges can be a determining factor of the high aluminum content recorded at point Ex2 during C1, because the increase of the turbidity induces an increase of the aluminum concentration in the mine water [73]. The high aluminum content at point Ex2 during C1 can also be linked to the pH of the mine waters, because the solubility of aluminum is low in waters with a pH close to neutrality between 7 and 7,5, while the precipitation of aluminum requires a pH greater than 5 [73,74].

Also, the aluminum can be related to the natural erosion phenomena of the mountain, because it comes mainly from the mechanical training of alumino-siliceous minerals, which are easily mobilized, present in amorphous gels (allophanes type) and / or watershed clays [75].

3.1.4. IRON

The iron concentrations recorded at the mine water discharges during the C2 are lower than those recorded during the C1, except at the station Ex 1 (Figure 7). Like aluminum, the iron concentrations recorded during the C1 and C2 analysis campaigns are below the limit recommended by the limit values of industrial discharges in surface or underground waters fixed at 5 mg/L, except at the station Ex 2, which represents a value of 25.5 mg/L during the C1, far exceeding the limit value.

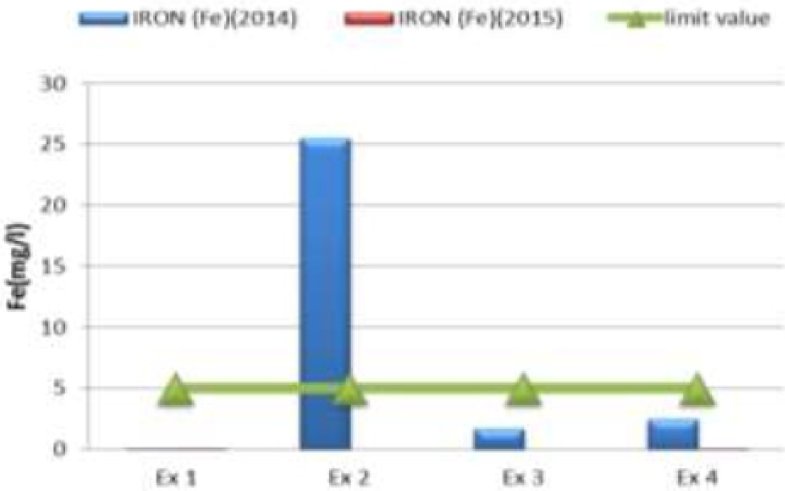

Figure 7. Evolution of the iron content of the mine water discharges during the C1 and C2 campaigns.

During the mining of a massive rock containing sulfide minerals, the pumping of the mine's dewatering in the surrounding lands an area that was previously saturated, which put the sulfide minerals in contact with the oxygen and the water of percolation. This induces the alteration of all readily oxidizable minerals, through the formation of sulfates and hydroxides, carbonates and other oxygenates characteristic of what is called the oxidation zone of mineral deposits. The Pyrite, which is the most widespread sulfide in the earth's crust, oxidizes to ferrous sulfate which, in the presence of free oxygen, is transformed into ferric sulfate [75]. This could explain the high concentration of Iron at the station Ex 2 because the deposit 2 is rich in pyrite [19,57,65,66,76].

3.1.5. MANGANESE

The Manganese concentration recorded values indicate an irregular contamination. Indeed, they vary, at the 4 stations, between a minimum value of 0.003 mg/L recorded in the station Ex 3 during the C2 and a maximum value of 8.78 mg/L noted in the station Ex 2 during the C1, thus exceeding the limit value fixed at 1 mg/L. Seasonal variability is recorded at the station Ex 1, which has a concentration of 0.075 mg/L during the C1 and a concentration of 7.35 mg/L during the C2 (Figure 8).

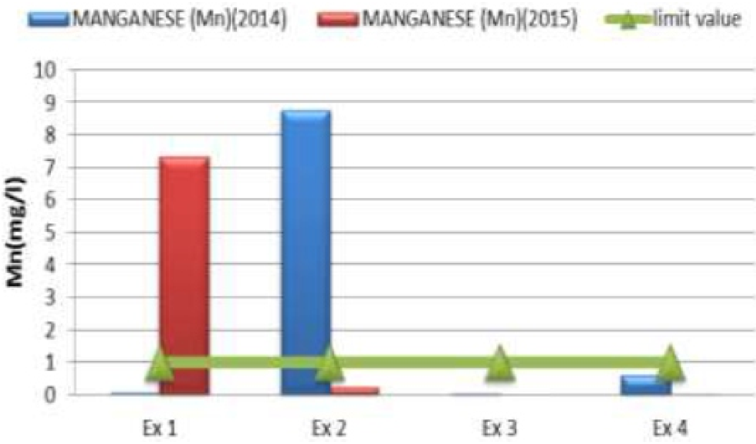

Figure 8. Evolution of the Manganese content of the mine water discharges during the C1 and C2 campaigns.

Like iron and aluminum, the high concentration of Manganese at the station Ex 2 during the C1 and at the station Ex 1 during the C2 can be related to the oxidation of pyrite [19,57,76], following the percolation of the mine's water through the mining cavities of sulfide lands [75].

The remarkable decrease in the concentration of aluminum, iron and manganese at the station Ex 2, between the C1 and C2 campaigns is due to the change of the geochemical background, this is being the case because when the depth of the mine increases the water circulates deeper in the mine, and its overall mineralization changes [61,70].

3.1.6. ARSENIC

The arsenic values recorded at the totality of the mine water discharges sampling stations do not exceed the limit values of industrial discharges in surface or underground waters set at 50 µg/l, except in the Ex 2 station which had a concentration above the standard during the C1. During the C1, they show significant variability from downstream to upstream of the mine, which varies between 83µg/l and 2.5µg/l at the Ex 2 and the Ex 1 stations respectively (Figure 9).

However during the C2, the variation of the arsenic contents is less important with values much lower than those recorded in the C1, and which vary between 25µg/l at the station Ex 3 and 3,6µg/l at the Ex 1 and Ex 4 stations.

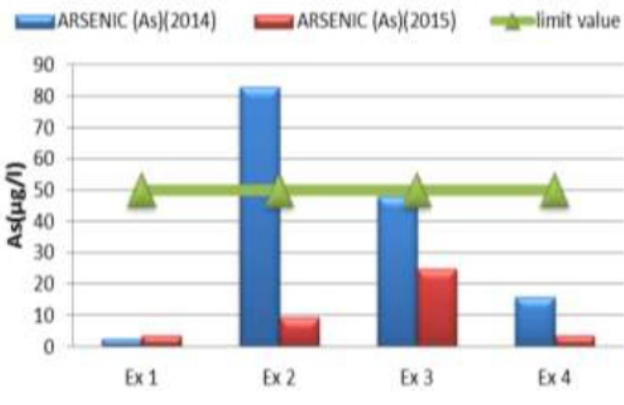

Figure 9. Evolution of the Arsenic content of the mine water discharges during the C1 and C2 campaigns.

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The arsenic ultimate source in the mine waste is the primary arsenopyrite in the ore concentrates. Arsenic is commonly associated with metallic mineral deposits. While arsenic is naturally mobilized from these deposits, mining and beneficiation of the deposits can significantly amplify arsenic mobilization. Once the ore has been excavated, processed, and discarded in waste rock piles and tailing, percolating rainwater can facilitate oxidation and dissolution of arsenic from the mine wastes and mine excavations. Dissolved arsenic can then be discharged into the environment with potentially toxic consequences for the downstream biota. Mining and tailings disposal promotes oxidative arsenic mobilization by increasing permeability and increasing contact between arsenic sulfides and oxygenated water. Hence, anthropogenic interference accelerates the natural processes of arsenic mobilization and dispersal into streams.

Arsenic is initially present in sulfide compounds such as arsenopyrite (FeAsS), orpiment (As2S3) or realgar (AsS) [77–81]. The arsenic contents in the waters vary according to the lithology crossed, the climate and the anthropic contribution [79]. And since it comes in different chemical forms (like many other elements), its speciation depends on the pH and the redox potential [82,83].

The visible decrease in the concentration of arsenic at point Ex 2 during C2, is probably linked to the decrease in the concentrations of Fe, Al and Mn in the mine water discharges of this point, because the oxyhydroxides of these elements constitute alongside clays and organic matter a significant fraction of the arsenic trapping during the weathering which plays an important role in controlling the concentration of dissolved arsenic [84–89].

3.1.7. LEAD, CADMIUM, COPPER, AND ZINC

The levels of lead, cadmium, copper and zinc recorded at the totality of the mine water discharges sampling stations, have a small spatial and temporal variability (Figure 10). They remain very low and do not exceed the limit values for industrial discharges set at 1000 µg / l for lead, 200 µg / l for cadmium, 3000 µg / l for copper and 5000 µg / l for zinc.

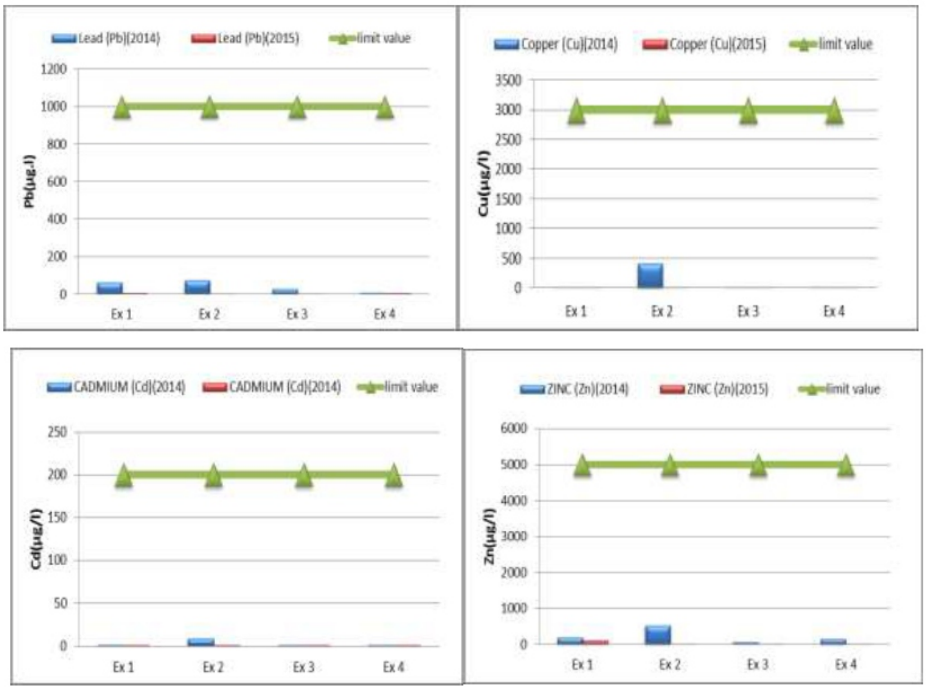

Figure 10. Evolution of lead, cadmium, copper and zinc contents of water discharges during the C1 and C2 campaigns.

In waters, lead (Pb) has a strong affinity for sedimentary particles including clays, oxy-hydroxides of iron and manganese, sulfides and organic matter [90]. It can also be associated with carbonates when the medium is poor in organic matter and in oxy-hydroxides of Fe or Mn [91].

While zinc (Zn) is in ionic form, it is complexed by organic ligands (fulvic and humic acids) or even associated with inorganic colloids. In waters with pH below 8, the concentrations of zinc in the cationic form (Zn^{2+}) are greater, while the neutral species $ZnCO_3$ is predominant in waters with pH above 8 [92]. Furthermore, the zinc is complexed with sulfates in waters with an acid pH and can precipitate in the form of sulfated salts under extreme acid conditions [93,94]. For the Cadmium (Cd) in waters and pH value below 8, it is present in the dissolved state as Cd^{2+} form, preferentially complexed by humic substances [95]. And in an anoxic environment, it precipitates with S^{2-} even at very low concentrations [24].

In waters the copper (Cu) is mainly found in divalent form Cu (II), while the monovalent form Cu (I) is present only at extremely low concentrations since it reacts to form metallic copper and Cu (II) ions. Cu (I) can be produced under reducing conditions and the majority of the compounds formed are insoluble [96,97].

The Copper in complexed form is associated with inorganic and organic ligands. This complexation of Cu by organic ligands strongly conditions its bioavailability, because the organically complexed copper is very stable [98]. The metallic cations (Pb, Zn, Cu and Cd) generally show low concentrations in the waters of mining lakes when the pH is alkaline [99]. This is the case of the HBM mine water discharges, which is located in limestone soils [38,55] where acidic waters are quickly neutralized by carbonates, and where most metals become insoluble and precipitate [100].

3.2. National studies

In morocco, currently there are active mines producing a variety of mineralization processes, and there have been many closed and abandoned mines since the 1970s. Recently, some studies have been interested in the environmental impact of abandoned mines and sites as well as the recovery of their waste. Let us cite those of [101] and [102], on the Kettara mine and [103] on the Sidi Bou Othmane mine in the Jebilet; we can also refer to those carried out in Haute-Moulouya [104–107]., in central Morocco on the Tighza mine [108], on the Mohammedia salt mine [109] and on the Jerrada mine [110]. The studies on zones near the mining centers of Aouli and Mibladan in Haut Moulouya have shown a negative impact of mining activities, especially the contamination of surface water, sediments, soil and plants [63,106,111,112], as well as pollution by heavy metals of surface water of Moulouya river [100,113].

The evaluation of the physico-chemical quality and the MTE load of the mine water discharges is an inseparable part of the evaluation of the impact of mining on the environment, because it can be indicative of the origin of any metal detected in excess in surface water, groundwater or sediments surrounding mines. However in most of the environmental impact studies the mine water discharges are considered as natural waters discharges from the mine, however the drainage of this water through the mine cavities can induce their load in MTE., which can have an impact on the environment once this mine water is discharged or infiltrated into the underground water.

Table 2. Comparative table of the average concentrations of metallic trace elements in the HBM water discharges and in the mine water discharges of other mines in Morocco.

	Average MTE concentrations (μg/L)					Industrial site	Study area	Exploited substance	Reference
	Pb	Cd	As	Cu	Zn				
Mine water discharges	23, 17	1, 4	23, 87	53, 81	131, 67	HBM	Sebou watershed	n. d	This Work
Mine lakes	27, 5	n. d	92,825	n. d	n. d	Zeïda Mine	Haute Moulouya	Pb	[111]
drainage water	n. d	n. d	n. d	58000	45000	Kettara Mine	Kettara River Jebilet	Fe-S	[102,116,117]
Mine lakes	31, 186	n. d	111, 202	n. d	n. d	Zeïda Mine	Haute Moulouya	Pb	[63]
Leachate of mine tailing	306, 875	9, 125	763	100686	8597	Kettara Mine	Kettara River Jebilet	Fe-S	[115]

n. d.: Undetermined value

In Morocco, in the majority of the impact of mining on the environment evaluation studies, the physico-chemical characterization and the evaluation of the contamination in MTE are focused on the evaluation of the water quality and sediments surrounding mining sites. In such studies, the designation of mine discharges is attributed to all liquid or solid mine discharges (spoil tip; dumps; ore processing residues; water from quarry lakes and infiltration at the foot of the tailings dam). As an example of the studies characterizing the quality of solid discharges from the mine or the ore processing plant, we can cite the work on the Tourtit and Ichoumellal mines [2], the Zeïda, Mibladen and Aouli mines [106,113], the Sidi Bou Othmane mine [103], the Kettara mine [101,102,114,115].

Since we are interested in the HBM mine water discharges, in our study the concentrations of metallic trace elements evaluated in this study were compared with some national studies (Table 2), which are concerned with the evaluation of metallic trace elements in mining areas and their concentrations in mine liquid discharges [63,102,111,115–117]:

The origin of the waters and their course define their hydro-chemical character and, hence the difference in MTE contents in mine liquid discharges compared to the levels in the HBM mine water discharges. In the case of the Zeïda mine, water is sampled at the level of the mining lakes, which is located at the foot of the spoil tip and the tailings dam. The arsenic and lead concentrations are higher than the levels recorded in HBM's mine water discharges. These discharges have a common character with the waters of the mining lakes of Zeïda which is the neutral pH to slightly alkaline influencing the solubility of the MTE due to the fact that the metallic trace element (Pb, Zn, Cd, Cu, ...) show high concentrations in acid mining lakes, while the MTE (As and Se) are generally at high concentrations in alkaline mining lakes [63,99].

For the drainage water from the kettara mine, samples were taken from various pits collecting runoff water of the tailings pond and runoff water of the waste rock [102,116,117]. These drainage waters have much higher copper and zinc contents than those recorded in the HBM mine water.

The leachate of the kettara mine tailings are obtained by mixing 150 g of tailings with 300 ml of distilled water (Ratio 1/2), with permanent agitation, and after a week, the filtration was carried out, then the measurements of the concentrations of MTE in the leachate water, these analyses show that the As and Pb contents are higher at the top of the pile of mining residues, which can be explained by the acidic pH on the surface of the pile of mining residues in direct contact with the oxygen. The values recorded in As, Pb, Cu, Cd and Zn at the leachate of the tailings of the kettara mine are much higher than those recorded at the HBM's water discharges.

The MTE concentrations in the HBM water discharges are the lowest compared to other liquid discharges from other mines, something which can be linked to several factors, including: the geochemical background of the mine, the waters contact time with the rocks, the nature of the residues that the water percolates through and finally the pH of the water which plays an important role in the degree of passage of the MTE in the aqueous phase.

3.3. International studies

The concentrations of metallic trace elements evaluated in this study were compared with some international studies (Table 3), which are concerned with the evaluation of metallic trace elements in mining areas and their concentrations in mine water discharges [118–120].

The average concentration of lead (Pb) recorded in the HBM water discharges is lower than the one noted in the mine water discharges of the abandoned Escarro mine in France, which was exploited between 1960 and 1991, according to the environmental impact study of the Escaro's mine developed in 1983 [118]. In terms of lead, the average concentration in the HBM mine's water is in second class after that of the Escaro mine, then in third class that of the Malines mine in France, and in the last class that of the Soughs mine in England.

Table 3. Comparative table of the average concentrations of metallic trace elements in the HBM water discharges and in the mine water of four other active and abandoned mines worldwide.

		Average MTE concentrations (µg/L)					Industrial site	Study area	Exploited substance	Reference
		Pb	Cd	As	Cu	Zn				
Morocco	Ex1 (C1)	61	1,1	2,5	4,2	190	HBM	Sebou watershed	n.d	This work
	Ex1 (C2)	5, 6	0, 5	3,6	2	115				
	Ex2 (C1)	72	8, 3	83	406	528				
	Ex2 (C2)	1, 7	0, 2	9,3	1 ,4	2, 2				
	Ex3 (C1)	28	0, 3	48	3, 3	60				
	Ex3 (C2)	1, 7	0, 2	25	1, 4	2, 2				
	Ex4 (C1)	9	0, 4	16	8, 8	143				
	Ex4 (C2)	6, 4	0, 2	3, 6	3, 4	13				
	Average	23, 17	1, 4	23, 87	53, 81	131, 67				
France		29	n. d.	2, 14	5	9, 28	Escarro mine	Languedoc Roussillon Têt watershed	CaF_2	[119]
		11, 12	2, 7	n. d.	n. d.	4,21	Malines mine	Saint-Laurent-le-Minier Hérault watershed	Pb, ZnS, PbS, Zn	[118]
England		10, 2	0, 84	n. d.	0, 56	160, 2	Soughs mine	Derbyshire Bugsworth watershed	Pb	[118]
Norway		n. d.	12800	280	574000	5640000	Killingdal mine	Sør-Trøndelag Gaula watershed	Cu Zn S	[120]

n. d.: Undetermined value

For the Cadmium (Cd), the average concentration recorded in the mine water discharges of the HBM is in third class after that of the Killingdal mine in Norway, and that of the Malines mine in France, and in the last class that of the Soughs mine in England. In terms of Arsenic (As), the average concentration in the HBM water discharges is in second class after that of the Killingdal mine in Norway, and in the last class that of the Escarro mine in France.

The average concentration of copper (Cu) in the HBM water discharges is in second class after that of the Killingdal mine in Norway, then in third class that of the Escarro mine in France, then in the last class that of the Soughs mine in England. And for the Zinc (Zn), the average concentration recorded in the HBM water discharges is in third class after that of the Killingdal mine in Norway, and that of the Soughs mine in England. In fourth class that of the Escarro mine in France then that of the Malines mine in France.

It should be noted that the physicochemical characterizations of mine waters compared to the HBM are developed as part of studies aimed at the sustainable management of mine water discharges and the reduction of their environmental impacts. For the rest of the mines, it is in the context of an environmental impact study for the continuation of exploitation for the Escarro mine, and in the context of the performance monitoring of the treatment station of mine water discharges for the Malines mine, and post-mine monitoring and impact assessment for the Soughs and the Killingdal mines. The differences among the average concentrations of MTE contained in the mines waters show the importance of the lithology of the host rock, rather than the mineralogy of the ore, for the quality of the mine water [120].

The oxidation of sulfide minerals to release heavy metals, sulfate and acid is the fundamental reaction characterizing acid mine drainage [60,121–123]. However, the quality of mines waters can be adversely affected by other parameters such as the kinetic factor because of the relatively slow rate of dissolution and oxidation of sulfide minerals compared to the rapid flux of limestone groundwater through the mine conduits [38,55]. And the solubility of heavy metals that is suppressed by the high alkalinity of water, as well as other parameters that may negatively influence the global quality of mine water discharges such as the salinity, the traces of explosives based on nitrogen oxidized to nitrates and the organic parameters [120].

The mine water discharges of the HBM are classified as one of the least charged mine water in terms of MTE compared to other mines (Table 3).

3.4. Synthesis

The physicochemical characterization of the mine water and the evaluation of their load in metallic trace elements (MTE) showed a small variability in time and space between the four stations sampled, and absenteeism of the acidic nature of mine's water. The majority of the analyzed mine waters presents important concentrations of sulfate. During the C1 at the point Ex2 theirs is contamination of Iron, Aluminum, Manganese and Arsenic. However, the concentrations of Pb, Cd, Zn and Cu elements remain conform and very low compared to the limit of standards. The monitoring of the overtake elements made it possible to identify the degree of contamination of the mine's water discharges, and to note an improvement in time in the mine water discharges quality. This variation in element concentrations between the C1 and C2 campaigns is due to the change of the geochemical background, because with the progress of the mining operations, the geochemical background changes, influencing the hydro-chemical composition of the percolated mine water through the walls of the mine before its rise to the surface of the ground, forming the final discharges.

The mine water discharges of the HBM are classified as one of the least charged mine water in terms of MTE concentration compared to other national liquid mine discharges and to other mine waters worldwide.

4. CONCLUSION

The evaluation of the quality of the discharges of mine water elaborated in this study for the first time, to our knowledge, at the level of the beht basin, sub-basin of Sebou, allowed to identify the quality of the discharges of mine water and their load in MTE in order to evaluate the impact of these discharges on the environment. Thus the evaluation of the mining contribution in the modification of the quality of the environment surrounding the Haut beht mine.

The mine water remains a reservoir of contamination able to drop in the aqueous phase other elements by the phenomenon of leaching and dredging in the wet phase. Therefore it presents a potential toxicological risk in the absence of specific means of sustainable management aimed at safeguarding the surrounding environment of the mine and mitigating the potential impact of the mine water discharges into the environment.

Despite the absence of contamination of the HBM water discharges, their pH-dependent nature draws attention to the possibility of an MTE loading of the sediments and the waters surrounding the mine. The potential impacts of the mine's water discharges on the quality of groundwater, surface water, and sediments will be the subject of other ongoing works.

The diagnosis elaborated through the analysis and the quantification of the different parameters and their impacts, allowed to draw up a first report on the variability of the mine's waters discharges quality and their potential impacts on the environment.

Thus, the monitoring of environmental indicators may be essential for all industrial activity to limit their potential impacts on the environment.

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Conflict of interest

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Impact of Sugar Mills Effluent on Environment Around Mills Area

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ABSTRACT

The discharge of untreated industrial effluents degraded water and soil, and the entire environment. The study aimed to evaluate the impacts of sugar mills effluent on the environment around the mills' area. A total of 120 effluents, soils, and water samples were collected three times a year over two years to analyze the physicochemical parameters. A field survey also was conducted on two hundred households of fourteen villages of the two Upazila in Joypurhat District of Bangladesh. The survey observed that majority of the people have negative opinions regarding the impacts of sugar mills effluents on fish, crops, and human health life. The higher BOD5 level in the effluents indicated that the decline in DO that the bacteria consumed the available oxygen in the water leading to the inability of fish and other aquatic organisms to survive in the water body. The study observed that the concentrations of Fe^{3+}, Mn^{2+}, and Pb^{2+} were found higher than the standard permissible limit of DoEBD (2003) indicating the severe environmental degradation occurred in the areas. The study observed that the surface water, groundwater, and soil were contaminated through the discharge of sugar mills untreated effluents severely degraded the environment of the areas.

Keywords: effluent; groundwater; harmful; surface water; soil; toxic

1. INTRODUCTION

Rapid industrialization brings pollutants into the environment that severely degraded the hydrosphere and atmosphere. The discharge of untreated industrial and domestic wastewater into the environment affects both soil and water quality. The disposal of industrial effluent is one of the most serious challenges all over the world as well as in Bangladesh [1]. Presently, only about 10% of industrial wastewater is being treated and the remaining portion is discharged into nearby water bodies [2,3]. The waste stream contains a complex mixture of toxic substances, predominantly natural and synthetic organic substances, including metals, trace elements, pathogens from domestic and industrial sectors that enters into streams, rivers, and other water bodies. The dissolved and suspended substances are deposited on the bed resulted in the degradation of water quality [4–6]. The severity of environmental degradation depends on the quality and quantity of discharge effluents into the soils and water bodies [7,8].

The most important effluent discharging industries are sugar mills, thermal power plants, paper mills textiles, distilleries, fertilizer units, electroplating plants, tannery industries, sago factories, oil refineries, pesticide, and herbicide industries. These industrial effluents containing heavy metals pose a serious threat to the ecosystem [9]. Brazil is at the top in the production of cane sugar countries followed by China, India, Thailand, Pakistan, and Mexico [10]. A large quantity of water is during the sugar manufacturing processes, and as a result, sugar mills discharge a large amount of wastewater.

The discharged effluents were mixed with different chemicals used during processing [11]. Bangladesh produces 137000 metric tons annually and ranked 67th position among 130 sugar-producing countries [12]. There are 17 sugar mills in Bangladesh; most of them were established in rural areas.

Joypurhat sugar mill is one of them. The Mills discharged untreated effluent is polluting the Tulshigongga River water. The environmental activists and some eco-friendly organizations have protested against river water pollution in the district. During the sugar harvest period, 10 sugar mills of the country discharge about 21405 cubic meter of wastewater daily. The rivers in Northern Bangladesh are polluting through the discharge of untreated industrial effluents, including the Padma, Soto Jamuna, Karatoa, Shok, Tanggon, Bengali, Tulshigongga, Narod, and Esamoti, rivers, and their tributaries. The wastewater of Joypurhat Sugar Mills Ltd is considered to be harmful to the fishes of about 75 km of canal and river areas. The effluents of the sugar industry in the area were discharged through small open drains into the main drain and were eventually fallen into the Shree River. They produce sugar as well as large amounts of wastewater. The sugar mills, on average, generate one cubic meter of wastewater per ton of crushed cane. The discharge of sugar mill's wastewater into the surface water bodies with a high TDS adversely affects aquatic life. The irrigation water for most of the Rabicrop received unsuitable water during the sugar production period in November- April around the sugar mill areas [13]. Human life is also affected by the awful effects of untreated sugar industrial effluents [14].

Researchers are closely monitoring the consequences of discharging the waste from the industries and looking for innovative solutions to the challenging problems. A complex mixture of harmful chemicals, both organic and inorganic, is discharged into the water bodies from the sugar mills generally without any treatment threatened the entire environment. Thus the study aimed to assess the impacts of untreated sugar mills effluents on soil, water, and human life. The specific objectives of the study were to (i) understand people perceptions of the impacts of untreated effluents, (ii) identify the pollutants in the discharge effluents, (iii) identify the pollutants and assess their fates and effects on the soil, surface water, and groundwater around the sugar mills areas.

2. MATERIALS AND METHODS

2.1. Study area

Joypurhat is a small district town in the northern part of Bangladesh with an area of 965.44 sq km. There are five Upazilas (administrative area) in this district. It is located at 25.100°N– 25°06′N and 89.033°E–89°02′E. There are 17 sugar mills industries in Bangladesh, and the Joypurhat sugar mill is one of them. Generally, industrial factories should set up in a distant place from an urban area. But Joypurhat sugar mills Ltd is attached with the Joypurhat town. Its daily sugarcane crashing power is 2032 mT (metric ton), and yearly sugar product power is 20320 mT. The untreated wastewater of the sugar mills is passing, through a tiled and non-tiled open drain. It passes through several villages and finally, falls into the Shree River. The study area map is shown in Figure 1.

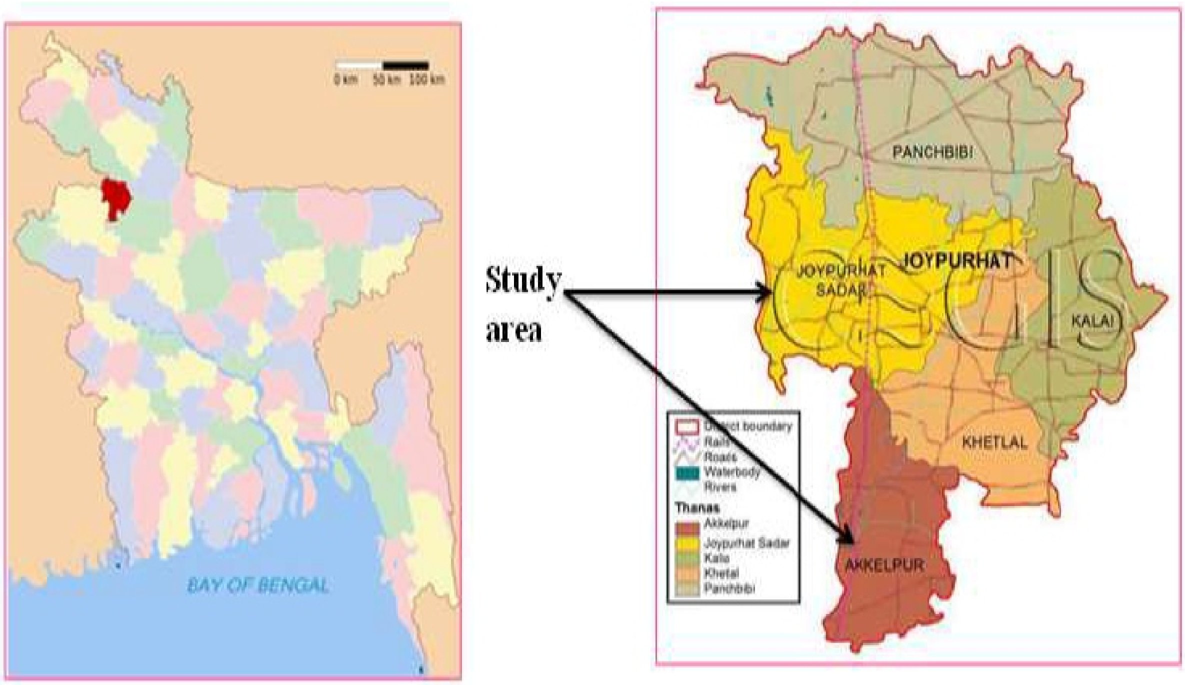

Figure 1. Map of the study area, Joypurhat, and Akkelpur Upazilas of Bangladesh.

2.2. Questionnaire survey

An extensive field survey was conducted to get public opinions and understand the present scenarios of discharging untreated effluents of the Joypurhat sugar mills in the District. Two hundred households in fourteen villages along the effluent discharged drain of Joypurhat Sadar and Akkelpur Upazilas, were participated in the survey. The questionnaire survey was conducted based on 36 questions on different categories, including education status, family member, sanitary condition, household fuel and electricity consumption, drinking water source, drainage pattern, crops, fish, and human diseases. The data were collected as precisely as possible from the survey and analyzed using statistical methods of analysis.

2.3. Sample collection

Four types of samples, i.e., effluent, surface water, groundwater, and soil were collected from two Upazilas (administrative areas), i.e., Joypurhat Sadar and Akkelpur to analyze physicochemical parameters. A total of 120 samples, including effluents, surface water, groundwater, and soil were collected three times a year (pre-production period, production period, and post-production period) for two years. The samples were collected from five different location points identified as L-1 to L-5. The first location point (L-1) was the outlet of the sugar mills and the second (L-2) to fifth (L-5) location points were selected at a distance of 2, 5, 10, 15 km, respectively from the outlet of sugar mills.

It was the head-end of the effluent discharging drain that fell into the Sree River. The major physicochemical parameters, including EC, DO, pH, BOD5, COD, Na^+, K^+, Ca^{2+}, Fe^{3+}, Zn^{2+}, Mn^{2+}, Cd^{2+}, Pb^{2+}, Cl^-, $No_3^{\,-}$, $So_4^{\,2-}$, and $Po_4^{\,3-}$ were considered in the study. A field survey was conducted on two hundred households of fourteen villages beside the effluent discharging drain passed through Joypurhat Sadar and Akklepur Upazila. The collected samples were characterized using standard methods of analysis and the experimental results were compared with the standards of wastewater (effluent), inland surface water, groundwater, and soil quality parameters which are the control variable that already exists.

2.4. Sample preparation

All the collected samples, i.e., effluent, surface water, groundwater, and soil were analyzed using the standard methods stated in American Public Health Association [15].

2.4.1. Effluent, surface water, and groundwater analysis

The study considered the parameters, including physio-chemical, cations, and anions for the effluents, surface water, and groundwater. The physio-chemical, parameters, including EC, DO, pH, BOD5, and COD; the major cations, including Na^{+}, K^{+}, Ca^{2+}, Fe^{3+}, Mn^{2+}, Cu^{2+}, Cd^{2+}, Zn^{2+}, and Pb^{2+}; and the anions, including Cl−, No3 −, So4 2−, and Po4 3− were determined using the standard methods of analysis [15].

2.4.2. Soil analysis

Soil samples were collected from the same selected location points as discussed above. The collected soil samples were transported to the laboratory of the Bangladesh Council of Scientific and Industrial Research (BCSIR) in Joypurhat for chemical analyses using the XRF instrument (ZSX Primus, Rigaku Corporation). The soil samples were mixed with the analytical grade organic binder (stearic acid), placed inside plastic rings, and pressed to form discs. These discs were placed in the XRF instrument (ZSX Primus) for the characterization of the soil sample. The soil samples were dried in an oven at 40 − C until a constant weight was obtained. This was done to drive away from the moisture which was harmful to the XRF instrument. The samples were mixed with the analytical grade organic binder (stearic acid), placed inside plastic rings, and pressed to form discs. These discs were placed in the XRF instrument (ZSX Primus, Rigaku Corporation) and scanned X-Ray diffraction with Cu Kα radiation using the proprietary EZ Scan software.

3. RESULTS AND DISCUSSION

The impacts of discharging the untreated sugar mills effluents on the environment were analyzed for various physicochemical parameters of the effluents, water, and soil, and the results are discussed here.

3.1. Public perception survey

Most of the people in the study have given their negative opinions regarding the impacts of sugar mills effluents on fish, crops, and human health life. They believed that the untreated effluents contained huge pollutants, which polluted the soil, waters, and human life around the sugar mills and effluent discharged drain adjacent areas. The survey report showed that the fish production in ponds, canals, and rivers was decreased about 67–73, 93–95, and 50–55%, respectively in the study areas due to the discharge of untreated effluents from the sugar mills (Table 1). Concerning the production of the crops, including rice, potatoes decreased to some extent. However, the production of some crops such as maize and sugarcane increased by 60 and 75%, respectively, due to the discharge of untreated sugar mills effluents (not shown in Table). The survey report also showed that about 21 and 18 % of respondents in Joypurhat Sadar and Akkelpur Upazila areas, respectively, were infected with skin diseases (Table 1).

Table 1. Field survey responses to agricultural production and human health.

Area/Upazila	Fish production decreased (%)			Crop production decrease (%)		Skin diseases	Human health
	Pond	Canal	River	Rice	Potato	(%)	effect (%)
Joypurhat	67	95	21	75	92	21	80
Akkelpur	73	93	18	69	84	18	69

3.2. Physicochemical parameters

The mean value of EC of the effluent, surface water, groundwater, and soil in the study varied from 488 to 1193 µS/cm (Table 2). The highest value was 1412 µS/cm found in the effluent samples indicating that the effluent contained high amounts of ions (not shown in Table 2). The higher EC values indicated the presence of huge amounts of ions of the effluents run into surface water and soil and ultimately polluted the surrounding environment.

The mean value of DO of the effluent, surface water, and groundwater in the areas was 0.48 to 8.74 mg/L, respectively (Table 2). The results showed that the DO of the surface water and groundwater were within the standard permissible limits [16–18]. However, the effluents' mean DO levels were below 1.5 indicated severe condition. When DO concentration is less than four (4) mg/L, aquatic animals are required to adjust their inhalation patterns and lower their level of activity. As the DO concentrations in the effluent were found to be very low, so it could have effects on the entire environment.

The pH is one of the most important operational quality parameters of water [19] and wastewater [20]. The observed pH values were within the range of the DoE-BD standard value. The pH of the effluent, surface water, and groundwater in the study areas was varied from 3.9 to 7.9 (not shown in Table 2). The observed pH values were found within the range of the DoE-BD (2003) standard [18].

The concentrations of BOD5 and COD in all samples were found to be higher than the IS-2000, NEQS-2000, and DoE-BD 2003 standard limits. The higher BOD5 values indicated the presence of high amounts of organic substances load in the effluents, which caused toxic effects on aquatic biota.

Under such a condition, no aquatic life can survive, except for the anaerobic micro-organisms [21]. A similar observation made by Saifi et al. (2011) supported the present finding [22].

The mean BOD5 in the effluent and surface water was varied from 5.05 to 209 mg/L (Table 2).

The higher BOD5 level in the effluents indicated the aerobic bacteria consumed the available oxygen in the water, which led to a decrease in fish and other aquatic organisms in water bodies. The mean COD in the effluent and surface water in the study was varied between 6.9 to 440 mg/L (Table 2). The COD is an important indicator of deterioration of the water quality from discharging the untreated industrial effluent.

Table 2. Mean values and standard deviations of physicochemical parameters in the effluent, surface water and groundwater from Oct. 2014 (Pre-production) - Apr. 2016 (Post-production) at different locations.

Parameters	Sample location	Effluent (Mean±SD)	Surface water (Mean±SD)	Groundwater (Mean±SD)
EC (µS/cm)	L-1	1193±266	788±107	550±256
	L-2	1183±273	778±103	521±240
	L-3	1125±296	771±102	507±234
	L-4	1110±291	767±103	493±222
	L5	1079±286	761±104	488±218

DO (mg/L)	L-1	0.48±0.23	6.3±1.86	8.74±0.23
	L-2	0.68±0.32	6.17±1.92	8.67±0.23
	L-3	1±0.39	6.16±1.91	8.60±0.3
	L-4	1.3±0.13	6.11±1.9	8.56±0.34
	L5	1.38±0.15	6.11±1.88	8.46±0.43
pH	L-1	5.15±0.95	6.9±0.14	7.14±0.98
	L-2	5.22±0.90	7.03±0.18	7.23±0.92
	L-3	5.24±0.91	7.2±0.17	7.27±0.92
	L-4	5.29±0.91	7.32±0.17	7.39±0.97
	L5	5.34± 0.88	7.55±0.104	7.57±1.08
BOD_5 (mg/L)	L-1	209±28.43	7.94 ±1.02	5.4±0.8
	L-2	204±26.74	7.84±1.01	5.29±0.78
	L-3	198±30.09	7.79±1.03	5.2±0.79
	L-4	194±29.2	7.71±1.02	5.09±0.75
	L5	186±31.19	7.68±1.0	5.05±0.75
COD (mg/L)	L-1	440±93.91	8.14±1.35	7.16±1.22
	L-2	434±93.48	8.02±1.32	7.09±1.22
	L-3	417±84.48	7.93±1.3	7±1.22
	L-4	407±79.67	7.83±1.28	6.96±1.23
	L5	383±64.36	7.77±1.25	6.9±1.21

The results showed that the average COD values of all effluent samples at five locations were found highest during the production period. The huge amount of organic and inorganic substances discharged through the effluent during the crushing process may be the cause of increasing the COD values. The results showed that COD values in the sugar mills effluent were found higher than the tolerance limits for inland surface water. The results illustrated that the high COD values indicated the presence of the high organic load and inorganic chemicals in the effluents. Akan et al. (2007) also reported that the higher levels of BOD and COD in sugar mills effluent contained organic and inorganic substances may cause toxic conditions with consequent adverse effects on aquatic biota [23]. Them higher concentrations of BOD and COD in all the samples indicated severe pollution of areas caused by the discharged effluent threatened the environment.

Table 3. Physicochemical parameters of effluents exceed the DoE-BD (2003) standard

Parameters	No. of sample exceed DoE value	% of sample exceed DoE value	Concentration ranges from to	DoE standard value
EC(μS/cm)	20	66.67	712–1412	1200
DO (mg/L)	30	100	0.2–1.6	4.5–8
BOD_5 (mg/L)	30	100.00	145–236	50
COD(mg/L)	30	100.00	297–508	200

Table 4. Major cations in effluent of Joypurhat Sugar Mills collected during Oct. 2014 (Pre-production) to Apr. 2016 (Post-production).

Elements (mg/L)	Sample Location	Period						Standard Permissible Limits		
		Preproduction 2014	Production 2015	Postproduction 2015	Preproduction 2015	Production 2016	Postproduction 2016	IS-2000	NEQS-2000	DoE-BD
Na	L-1	0.426	0.687	0.528	0.431	0.689	0.536	-	-	200
	L-2	0.418	0.656	0.519	0.421	0.674	0.525			
	L-3	0.405	0.594	0.498	0.409	0.612	0.508			
	L-4	0.394	0.575	0.496	0.398	0.588	0.498			
	L-5	0.382	0.533	0.487	0.390	0.536	0.489			
K	L-1	4.255	4.997	4.964	4.316	5.008	4.892	-	-	12
	L-2	4.248	4.972	4.958	4.308	4.993	4.886			
	L-3	4.230	4.928	4.917	4.298	4.972	4.874			
	L-4	4.219	4.864	4.840	4.272	4.916	4.859			
	L-5	4.211	4.785	4.753	4.254	4.894	4.843			
Ca	L-1	27.99	38.13	37.98	28.12	39.31	38.75	200	200	75
	L-2	27.88	38.12	37.86	27.91	39.27	38.63			
	L-3	26.34	37.89	36.77	26.77	38.62	37.81			
	L-4	25.87	36.73	35.61	26.21	37.54	36.32			
	L-5	24.72	35.61	34.43	25.13	36.12	35.15			

Note: IS-2000: Indian Standard -2000; NEQS- 2000; National Environmental Quality Standard-2000; DoE: Department of Environment, Bangladesh, 1997.

Table 3 shows the percentage of samples that exceeded the DoE-BD standard limit. The study results illustrated that all the samples belong to the surface and groundwater for the physicochemical parameters were found within the DoE-BD permissible standard. However, the effluents for EC, Do, BOD, and COD were exceeded 66.67 to 100% samples indicating the discharged effluent might harm the environment around the sugar mills effluent discharged areas.

3.3. Cationic parameters

The metals have adverse effects on crop production due to the danger of bioaccumulation and bio-magnification in the food chain. There is also the threat of superficial and groundwater pollution. The fate and transfer of heavy metals in the soil were depended considerably on the chemical form and speciation of the metal [24]. Table 4 shows a detailed analysis of some major cations, i.e., Na^+, K^+, and Ca^{2+} in the effluent samples. The concentration of the cations was found within the permissible standard of DoE-BD. The concentration of all cations of the effluent, surface, and groundwater was found higher in the production period than in the other two periods (not shown in Table 4). However, the concentration of these cations was found within the permissible limit recommended by the DoEBD (2003) (not shown in Table).

According to Table 5, the most common heavy metals found in the effluents at Joypurhat Sadar and Akkelpur Upazila areas in the order of abundance are Fe^{3+}> Mn^{2+}> Zn^{2+}> Cu^{2+}> Pb^{2+}> Cd^{2+}. However, However, in the soil, the dominant cations followed the order as Fe^{3+}>Mn^{2+}> Zn^{2+}> Pb2+>Cu^{2+}> Cd^{2+}. This distribution of heavy metals in soils was believed to be controlled by many ways such as mineral precipitation, dissolution, ion exchange, adsorption, and desorption, aqueous complication, biological immobilization, mobilization, and plant uptake [25]. The concentrations of Zn, Cu, and Cd in all samples were found below the permissible limit of IS-2000, NEQS-2000, and DoE-BD standards for discharged effluents.

The analysis results showed that the maximum concentrations of iron (Fe) in the effluent, surface water, groundwater were 13.1, 7.5, and 5.3 mg/L, respectively, found during the study period (Table 6). About 100% of samples exceeded the DoE-BD standard values of the effluents and groundwater samples, and about 67% of surface water samples exceeded the DoE-BD standard value for iron concentration (Table 6). Anaerobic groundwater may contain iron (II) at concentrations up to several milligrams per liter without discoloration or turbidity in the water when directly pumped from a well. Taste is not usually noticeable at iron concentrations below 0.3 mg/L, although turbidity and color may develop in piped systems at levels above 0.05–0.1 mg/L [26]. Laundry and sanitary ware stain at iron concentrations above 0.3 mg/L. Iron also promotes undesirable bacterial growth ("iron bacteria") within a waterworks and distribution system, resulting in the deposition of a slimy coating on the piping. The mean concentration of Mn^{2+} in the effluent and surface water was found within the range of DoE-BD standard limits. But it exceeded the standard level in groundwater. The highest concentration of Mn^{2+} was found to be 1.08 (Table 6).

Table 5. Mean and standard deviations of heavy metals in effluent, surface water groundwater and soil from Oct. 2014 (Pre-production) to Apr. 2016 (Post-production) at different locations.

Cations (mg/L)	Sample location	Effluent (mg/L) Mean±SD	Surface water (mg/L) Mean±SD	Groundwater (mg/L) Mean±SD	Soil (mg/kg) Mean±SD
Fe^{3+}	L-1	10.17±3.48	4.32±2.9	3.36±1.65	66.5±16.08
	L-2	9.8±3.46	4.17±2.8	3.26±1.61	64.68±15.91
	L-3	8.67±3.65	3.84±2.5	3.0±1.40	61.02±16.72
	L-4	7.54±3.62	3.60±2.39	2.8±1.25	56.14±20.2
	L-5	6.68±3.25	3.13±2.05	2.81±1.35	52.55±19.64
Mn^{2+}	L-1	1.74±0.9	1.48±0.46	0.92±0.17	5.16±1.67
	L-2	1.71±0.89	1.45±0.45	0.83±0.18	4.99±1.72
	L-3	1.66±0.86	1.35±0.4	0.76±0.24	4.54±1.49
	L-4	1.64±0.84	1.18±0.3	0.7±0.21	4.12±1.36
	L-5	1.61±0.83	1±0.17	0.68±0.2	3.6±1.11
Zn^{2+}	L-1	0.09±0.01	0.07±0.03	0.05±0.03	1.5±0.97
	L-2	0.09±0.01	0.07±0.02	0.05±0.03	1.06±0.99
	L-3	0.09±0.01	0.06±0.02	0.04±0.03	0.29±0.02
	L-4	0.09±0.01	0.06±0.02	0.04±0.03	0.24±0.03
	L-5	0.08±0.01	0.05±0.02	0.03±0.02	0.19±0.02
Cu^{2+}	L-1	0.08±0.02	0.11±0.056	0.004±0.001	0.141±0.014
	L-2	0.08±0.02	0.097±0.056	0.004±0.001	0.116±0.005
	L-3	0.07±0.02	0.09±0.052	0.003±0.001	0.098±0.01
	L-4	0.06±0.01	0.081±0.048	0.003±0.001	0.087±0.004
	L-5	0.05±0.005	0.068±0.046	0.003±0.001	0.076±0.006
Cd^{2+}	L-1	0.003±0.0005	0.004±0.002	0.003±0.0008	ND
	L-2	0.002±0.0008	0.004±0.001	0.003±0.0005	ND
	L-3	0.002±0.0009	0.003±0.001	0.003±0.0005	ND
	L-4	0.002±0.0009	0.003±0.001	0.002±0.0005	ND
	L-5	0.002±0.0009	0.002±0.0009	0.002±0.0008	ND
Pb^{2+}	L-1	0.147±0.007	0.072±0.031	0.065±0.03	0.45±0.32
	L-2	0.146±0.003	0.070±0.031	0.063±0.03	0.44±0.31
	L-3	0.140±0.004	0.070±0.031	0.061±0.03	0.42±0.31
	L-4	0.139±0.0123	0.069±0.031	0.058±0.03	0.41±0.30
	L-5	0.137±0.005	0.067±0.031	0.057±0.03	0.40±0.30

Note: *ND: Not detected

The mean value of Pb in the effluent, surface water, and groundwater samples in the areas was 0.069, 0.06, and 0.45 mg/L, respectively (Table 5). About 67% of the effluent samples exceeded the Pb concentration of the DoE-BD standard indicated possible human health effects (Table 6). One of the major mechanisms of Pb exerts the toxic effect is through biochemical processes that include the ability of Pb to inhibit or mimic the actions of calcium and interact with proteins [27]. Within the bones, Pb is integrated into the mineral in place of calcium. Lead (Pb^{2+}) binds to biological molecules and thereby intrusive with their utility by several mechanisms. Lead (Pb^{2+}) may also compete with necessary metallic cations for binding sites, inhibiting enzyme activity, or shifting the movement of essential cations such as calcium [27]. Lead (Pb^{2+}) can accumulate in the human body through the food chain and causes harmful effects on various human organs [2,9,28]. Besides, some of the toxic metal ions exceeded the standard permissible limits. These toxic metal ions and their compounds cause extremely harmful to human health through water and foodstuff. As the human consume the toxic metal ions, they may accumulate in bones and other organs. Thus, it causes diseases like diarrhea, carcinogenic, renal disorder, and diseases of kidneys, artillery, and nervous system [4,29]. The study observed that the presence of toxic metal ions along with the other ions in the effluents would have increased the contamination level in the surface and groundwater of the area. These toxic metal ions and their compounds caused extremely harmful to human health through water and foodstuff. As the human consume the toxic metal ions, might be accumulated in bones and other organs. The study observed that the surface water, groundwater, and soil were contaminated through the discharge of sugar mills untreated effluents in the study area, and the contamination process will continue in the future.

Table 6. Heavy metals parameters exceeded DoE-BD (2003) standard.

Parameters (mg/L)	Type of sample	% of sample exceed DoE value	Maximum concentration	DoE-BD standard value
Fe	Eff	100 .00	13.11	2.0
	SW	66.67	7.52	2.0
	GW	100.00	5.33	0.3–1.0
Pb	Eff	100	0.146	0.1
	GW	33.33	0.088	0.05
Mn	GW	100.00	1.085	0.05–0.1

3.4. Impacts Anionic parameters

The highest mean concentration of Cl^{-} in the effluent, surface water, and groundwater samples were 81.52, 51.96, and 57.36 mg/L, respectively (Table 7). The highest mean concentration of SO_4^{2-} in the effluent, surface water, and groundwater samples were 92.62, 58.35, and 50.05 mg/L, respectively (Table 7.). The highest mean concentration of No^{3-} in the effluent, surface water, and groundwater samples were 37.75, 2.5, and 2.34 mg/L, respectively (Table 7).The highest mean concentration of Po_4^{3-} concentrations of the effluent, surface water, and groundwater samples in the study area were 23.43, 1.21, and 1.03 mg/L, respectively. All the values were found within the standard permissible limits of IS-2000, NEQS-200, and DoE-BD (2003) standards [16–18]. Therefore, the anionic parameters would have caused any harm to human life and the environment.

Table 7. Mean values and standard deviations of anionic parameters in effluent, surface water and groundwater during Oct. 2014 (Pre-production) - Apr. 2016 (Post-production) at different locations.

Parameters	Sample location	Effluent (mg/L) Mean±SD	Surface water (mg/L) Mean±SD	Groundwater (mg/L) Mean±SD
Cl^-	L-1	81.52±3.92	51.96±11.13	52.24±13.59
	L-2	76.39±6.49	51.16±10.78	53.55±13.66
	L-3	68.7±9.19	49.96±10.95	54.85±13.37
	L-4	61.79±12.04	49.07±10.93	56.45±13.01
	L-5	59.02±12.61	48.04±10.79	57.36±12.69
SO_4^{2-}	L-1	92.62±2.67	58.35±11.94	50.05±5.53
	L-2	90.19±2.72	57.42±12.25	48.24±6.64
	L-3	88.23±1.96	56.42±12.37	47.64±6.59
	L-4	81.89±7.16	55.36±12.69	46.33±6.75
	L-5	78.83±8.26	54.46±13	45.49±6.65
NO_3^-	L-1	37.75±3.06	2.5±0.63	2.34±0.24
	L-2	36.3±2.49	2.44±0.62	2.26±0.22
	L-3	33.76±1.37	2.32±0.6	2.16±0.25
	L-4	32.15±1.58	2.21±0.57	2.11±0.24
	L-5	30.55±1.95	2.15±0.56	2.04±0.27
PO_4^{3-}	L-1	23.43±7.11	1.21±0.28	1.03±0.43
	L-2	22.03±6.82	1.19±0.27	1.01±0.43
	L-3	21.09±6.49	1.16±0.27	0.99±0.42
	L-4	20.35±6.41	1.13±0.27	0.97±0.42
	L-5	19.51±5.94	1.06±0.27	0.95±0.41

3.5. Impacts on Human Health

The study results illustrated that there were some toxic metal ions, including Fe^{3+}, Pb^{2+}, and Mn^{2+} in the effluent, surface water, groundwater, and soil that exceeded the permissible limit of the DoEBD standard. Besides, a large amount of the toxic metal ions were present in all various samples that exceeded the standard permissible limits concerned public health. These toxic metal ions and their compounds cause serious harm to human health through water and foodstuff. A flow diagram shows how the sugar mills effluent contaminated soil and water, and the consequences of the results cause harm to human and aquatic life (Figure 2). As the human consume toxic metal ions through foodstuff, they may accumulate in bones and other organs. Thus, it causes diseases like diarrhea, carcinogenic, renal disorder, kidney diseases, artillery, and nervous system.

The study results showed that surface water and groundwater were contaminated to some extent and are likely to be continued in the future due to randomly discharged the untreated effluents around the sugar mills effluent discharged area. The study suggested that every sugar mill has to be installed an effluent treatment plant (ETP) as well public awareness programs should be taken for the inhabitants around the mills' areas to reduce the pollution level and save human health and the environment.

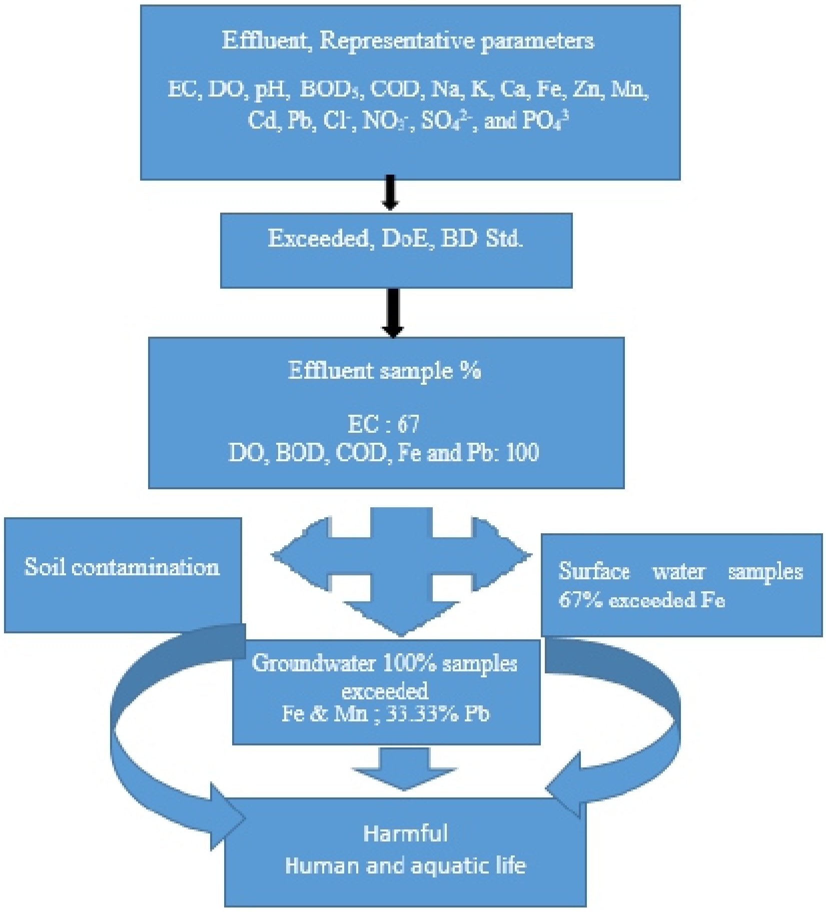

Figure 2. Representative parameters in the sugar mills effluents threaten for human and aquatic life through mobilization into surface and ground water.

4. CONCLUSIONS

The survey results illustrated that most of the people in the study areas have given their negative opinions regarding the impacts of sugar mills effluents on fish, crops, and human health life. They believed that the untreated effluents contained huge pollutants, which polluted the soil, waters, and human life around the sugar mills and effluent discharged drain adjacent areas. The higher BOD level in the effluents illustrated that the bacteria consumed the available oxygen in the water that declined the DO in water and reduced the survival condition for fish and other aquatic organisms. The study observed that some toxic metal ions, including Fe^{3+}, Mn^{2+}, Pb^{2+}, Cu^{2+}, Zn^{2+}, and Cd^{2+} were present in the effluent, surface water, groundwater, and soil. The study observed that the Pb^{2+} concentration of samples was exceeded the DoE-BD standard. Hence, the higher concentration of lead (Pb^{2+}) can accumulate in the human body through the food chain and causes harmful effects on various human organs. The study observed that the surface water, groundwater, and soil were contaminated through the discharge of sugar mills untreated effluents in the study area, and hence, immediate steps should be taken to treat the effluents before discharging into the environment.

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Conflict of interest

The authors declare no conflict of interest.

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