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RISK ASSESSMENT AND REHABILITATION POTENTIAL OF MUNICIPAL SOLID WASTE LANDFILLS IN BALI PROVINCE, INDONESIA

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ABSTRACT: As the final stage of waste management, the landfill has long been a focal point. Yet, the operation does not go in accordance with approved regulation which results in polluting. In response to that, Integrated Risk-Based Approach (IRBA) was conducted. IRBA is a decision-making method in closing and rehabilitation of open dumping through environmental risk assessment. Evaluated aspects on IRBA comprise of the technical aspect, environmental impact, and social aspect (particularly impact for society). Considered parameters in IRBA analysis are categorized into three which are: location (20 parameters), waste (4 parameters), and leachate (3 parameters). This research is focused on the risk index of a landfill in Bali Province which covers 10 landfills spread in Bali Province. Two of them are Regional landfill which is Sarbagita Regional landfill and Bangli Regional landfill; the others are City/Regency landfill which includes Bengkala landfill, Temesi landfill, Peh landfill, Linggasana landfill, Sente landfill, Jungut Batu landfill, Biaung landfill, and Mandung landfill. The higher the risk index, the higher the risk of polluting the environment which implies the need for further action, either by closing or rehabilitating the landfill. The highest risk index reached in Bali Province is 664.8 by Sarbagita Regional landfill and the lowest is 420.7 by Bangli landfill.

Keywords: Polluting hazard, Bali Province, IRBA, Municipal solid waste landfill

1. INTRODUCTION

Bali province is a global tourism area in Indonesia. Along with the increase in tourism activities, the waste generation in Bali Province also increased. Waste management in Bali Province still relies on landfill leads the shorter lifespan of the landfill than it should be. Most landfills are operated by open dumping method which results in high polluting potential toward the environment. Several landfills also not yet equipped with an appropriate facility such as drainage system, methane gas collection, and leachate management which indicate a highly probable risk of polluting the environment.

This waste management problem becomes a challenge for management stakeholder, in this case, the government to keep trying to increase waste management and service from the source to reach the target of Policy and National Strategy of Household Waste which written in Presidential Decree No. 97 the Year 2017. The decree states that the target of waste reduction is up to 30% of waste generation and 70% of waste management in 2025 without causing other polluting impacts in final processing site as the concluding management process.

Generally, household waste generation comprises of food waste, plastic waste, paper waste, glass, iron, hazardous and toxic waste (HTW) and other waste that could contaminate ground and groundwater, through leachate water. Leachate water occurs when the water infiltrated in landfill make contact with waste [1]. The leachate water could cause contamination of groundwater, surface water, agriculture, and nature's ecosystem; particularly when leachate is not managed properly and spread to the environment [2]. Moreover, in several developing countries, landfill location is close to the local residence which leads to direct impact for public health through groundwater contamination.

Aside from the possibility of pollution from leachate water, there is also a potential of air polluting through produced gas emission. Gas emission of landfill generally comprised of methane, carbon dioxide, water vapor, and non-methane organic compounds (NMOCs) [3]. The landfill also is the main source of direct emissions with 268,463 tonnes of CO_{2eq} and indirect impact with 1,694 tonnes of CO_{2eq} [4]. Although NMOCs only contributes less than 1% (V/V) of gas emission's total volume in a landfill, yet the effect of NMOCs toward human's health cannot be overlooked [5].

At present, various countries have noticed that their waste management methods are incompatible with sustainable development goals. Pollution assessment is an imperative tool to measure the level of environmental pollution and the level of pollution reduction [6]. Thus, with the high existing potential of pollution, there must be an assessment of the pollution impact. The first step in developing municipal solid waste landfills includes rehabilitation, especially in landfills with high pollution potential. Landfill rehabilitation is a recovery from a poorly managed landfill in order to increase landfill service life [7]. Moreover, the unmanaged landfill will be at risk of contamination from leachate, where with a high COD value, it will have a long-term impact on the landfill [8] should be closed.

2. BACKGROUND

2.1 Case Study

Bali Province is comprised of 1 (one) big island and 3 (three) small islands which are Nusa Penida, Nusa Lembongan, and Nusa Ceningan Island. Bali Province consists of 9 (nine) city/regency which are Badung Regency, Bangli Regency, Buleleng Regency, Gianyar Regency, Jembrana Regency, Karangasem Regency, Klungkung Regency, Tabanan Regency, and Denpasar City. The total population of this province in 2017 is 4.2 million and around 4.9 million tourists from around the world who come to visit tens of tourist destination in Bali Province [9]. The location of Bali Province in Indonesia map as shown in Fig. 1.

Fig. 1. Bali Province Location, Indonesia

Geographically, Bali Province is located at 8°3'40" - 8°50'48" South Latitude and 114°25'53" - 115°42'40" East Longitude. The relief and topography of Bali Island are mountainous areas which stretch from west to east in the middle of the island. Bali Province is located between Java Island and Lombok Island. The physical boundaries are as follow:

- North: Bali Sea
- East: Lombok Strait
- South: Indonesia Strait
- West: Bali Strait (East Java Province)

Most of waste management activity in Bali still uses the old paradigm which is collect-transport-dispose. Landfilling in a landfill is the most relied managing method in Bali Province. Bali Province has 10 landfills which serve 9 city/regency. In 2018, 60.99% or 1,432 ton/day of mixed waste which dominated by food waste is accommodated in the 10 landfills. Aside from transporting service provided by the government, there is also transporting service administered by private and informal sector who then sort waste with economic value to be sold or recycled. The demand to enhance waste management service, in general, is able to push the government to shift some services to the private sector [10].

The lack of municipal solid waste reduction results in large waste generation in landfills. Some of the landfill conditions are almost full and visually, the condition of the landfill is very poor. Leachate produced from 10 landfills is processed biologically by processing ponds which are anaerobic, facultative, and maturation ponds. The 10 landfills also have not managed the methane gas produced. The organic fraction of municipal solid waste greatly contributes to the release of terpenes, acids, esters, and NH_3 [11].

2.2 Impact

Final processing of waste has become a common predicament, especially in developing countries with an increase in population, economic level, a rate of urbanization and industrialization, accompanied by deficient waste management. Officers of landfill and locals need to understand and aware of health hazard potential from making direct contact with landfill. In Asia's developing countries, the potential of health risk from landfill gas emission has not yet been noticed due to limited observation data [5]. Moreover, usually in a landfill, the waste has not yet been categorized and already exposed to the environment for several days or weeks before compressed properly and covered with cover soil [12]. This leads to landfill becomes the primary source of carcinogenic material [5].

The risk of the landfill is also probable in polluting surrounding groundwater. Groundwater is one of the main sources for locals' drinking water and usually has better quality than surface water due to self-cleaning process through the ground [13]. Insufficient management of landfill made the process of flushing the organic compounds, metal, and hazardous and toxic waste by the rainwater possible made water pollution through leachate water percolation.

3. MATERIALS AND METHOD

Materials and methods of this research including:

a. Leachate Sampling

Leachate water in landfills was taken from leachate treatment ponds in the form of stabilization ponds. becaus of the quality of the last pond that would be released into bodies of water around the landfill.

b. Waste Composition Sampling

The sampling of waste composition was conducted in 10 landfills through categorizing waste into 10 types of waste which are kitchen waste, leaf/plant waste, plastic, paper, metal, rubber and leather, textile, glass, hazardous waste, and other types of waste based to SNI 19-3964-1994 guidelines.

c. Field Observation

Field observation was conducted to assess the existing condition of 10 landfills including their operational and facilities to support a good environmental quality around the landfill.

d. Interview and Literature

The interview was conducted toward related stakeholders regarding landfill data and surrounding areas.

e. Decision Tool

Integrated Risk-Based Approach (IRBA) is a decision-making tool developed in 2005 to rehabilitate landfill including sites with a high risk of health, maximum environmental impact, and sensitive public awareness [7]. Risk index for landfill is calculated cumulatively from values which considered contribute to environment polluting. The risk index encompasses attribute weight index and sensitivity as can be seen in Table 1. The value of each landfills risk index can be measured by multiplying the attribute weight with sensitivity index that defines from observation and interview. The conclusion that determines the level of hazard and recommended action then chosen by a hazard evaluation table based on the risk index as can be seen in Table 2.

Table 1. Decision-making tool, IRBA [14]

S/N	Attribute	Attribute Weightage	Sensitivity index 0.00-0.25	0.25-0.50	0.50-0.75	0.75-1.00
I – Site-specific criteria						
1.	Distance from nearest water supply source (m)	69	>5000	2500–5000	1000–2500	<1000
2.	Depth of filling of waste (m)	64	<3	3–10	10–20	>20
3.	Area of the landfill (Ha)	61	<5	5–10	10–20	>20
4.	Groundwater depth (m)	54	>20	10–20	3–10	<3
5.	Permeability of soil (1 x 10^{-6} cm/s)	54	<0.1	1–0.1	1–10	> 10
6.	Groundwater quality	50	Not a concern	Potable	Potable if no alternative	Non-potable
7.	Distance to critical habitats such as wetlands and reserved forest (km)	46	>25	10–25	5–10	<5
8.	Distance to the nearest airport (km)	46	>20	10–20	5–10	<5
9.	Distance from surface water body (m)	41	>8000	1500–8000	500–1500	<500
10.	Type of underlying soil (% clay)	41	>50	30–50	15–30	0–15
11.	Life of the site for future use (years)	36	<5	5–10	10–20	>20
12.	Type of waste (MSW/HW)	30	100% MSW	75% MSW + 25% HW	50% MSW + 50% HW	>50% HW
13.	Total quantity of waste at site (tons)	30	<104	104–105	105–106	>106
14.	Quantity of wastes disposed (tons/day)	24	<250	250–500	500–1000	>1000
15.	Distance to the nearest village in the predominant wind (m)	21	>1000	600–1000	300–600	<300
16.	Flood proneness (flood period in years)	16	>100	30–100	10–30	<10
17.	Annual rainfall at site (cm/year)	11	<25	25–125	125–250	>250
18.	Distance from the city (km)	7	>20	10–20	5–10	<5
19.	Public acceptance	7	No public concerns	Accepts dump rehabilitation	Accepts dump closure	Accepts dump closure and remediation
20.	Ambient air quality – CH4 (%)	3	<0.01	0.05–0.01	0.5–0.1	>0.1
II – Related to characteristics of waste at the landfill						
21.	Hazardous contents in waste (%)	71	< 10	10–20	20–30	> 30
22.	Biodegradable fraction of waste at site (%)	66	< 10	10–30	30–60	60–100
23.	Age of filling (years)	58	> 30	20–30	10–20	< 10
24.	Moisture of waste at site (%)	26	< 10	10–20	20–40	> 40
III – Related to leachate quality						
25.	BOD of leachate (mg/l)	36	<30	30–60	60–100	>100
26.	COD of leachate (mg/l)	19	<250	250–350	350–500	>500
27.	TDS of leachate (mg/l)	13	<2100	2100–3000	3000–4000	>4000

Table 2. Criteria for hazard evaluation based on the risk index [14]

S/N	Overall score	Hazard evaluation	Recommended action
1	750–1000	Very high	Close the dump with no more landfilling in the area. Take remedial action to mitigate the impacts
2	600–749	High	Close the dump with no more landfilling in the area. Remediation is optional
3	450–599	Moderate	Immediate Rehabilitation of the landfill into sustainable landfill
4	300–499	Low	Rehabilitate the landfill into sustainable landfill in a phased manner
5	<300	Very low	Potential Site for future landfill

4. EXISTING CONDITION

Bali Province has 10 (ten) landfill to serve 9 (nine) city/Regency. Plotting of landfill location in a map of Bali as shown in Fig. 2.

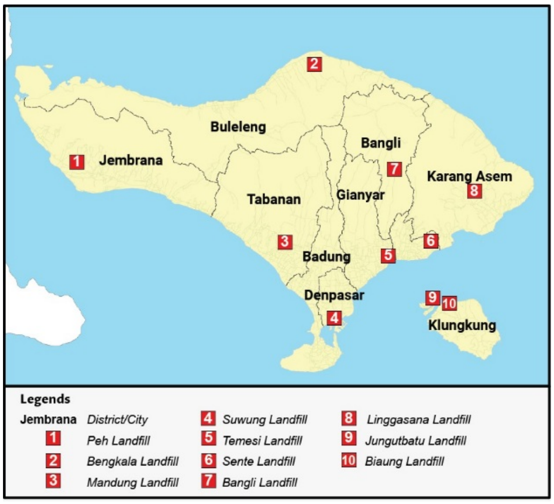

Fig. 2. Landfill plotting Location in Bali Province

Two of ten final disposal sites are regional landfill which is Sarbagita Regional landfill that serves Denpasar City, Badung Regency, Gianyar Regency, and Tabanan Regency. Bangli Regional landfill which supposes to serve Banglli Regency and Klungkung Regency. The other eight landfills only serve one city/Regency which is landfill Peh which serves Jembrana Regency; Temesi landfill which serves Gianyar Regency, Mandung landfill which serves Tabanan Regency, Linggasana landfill which serves Karangasem Regency, Bengkala landfill which serves Buleleng Regency, and 3 (three) other landfills are in Klungkung Regency for waste produced by citizens of Klungkung Regency which are Sente landfill, Jungut Batu landfill, and Biaung landfill.

The average distance from the landfill to the center of serviced city/regency is 15-25 KM. In recent times, five of ten landfills are almost filled to the brim which are Temesi landfill, Mandung landfill, Liggasana landfill, Sarbagita Regional landfill, and Bengkala landfill. The other two landfills are in overload condition which is Peh landfill and Sente landfill. The rest of landfills which are Bangli Regional landfill, Jungut Batu landfill, and Biaung landfill are in good condition, relatively empty, and can still be final processing site.

From the ten landfills, the biggest landfilling area is in Sarbagita Regional landfill with 5.5 Ha, followed with Bangli Regional landfill 3.77 Ha. In other landfills, the size of landfilling is around 1-2.5 Ha and varied according to the existing landfilling condition.

4.1. Waste Composition

Waste dumped in landfill has a different variety which determined by the source of the waste generation itself. the landfill which is the final processing site receives the waste from various sources of waste generation located in each service coverage. Characteristics and composition contained in the waste in each landfill will be in accordance with locals' characteristics. The average landfill waste composition as shown in Fig. 3.

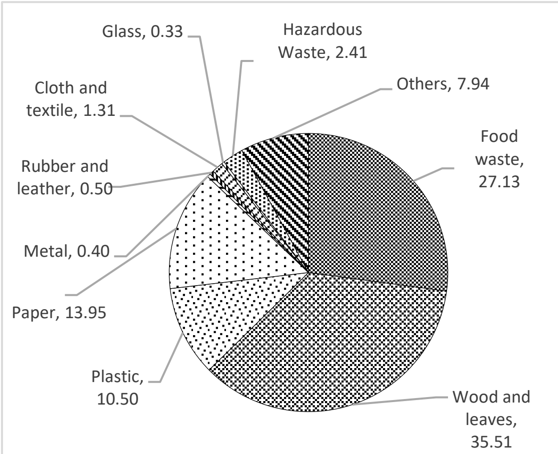

Fig. 3. The average landfill waste composition in Bali Province

It is obtained that the average of a landfill in Bali Province is dominated by leaf/plant waste with 35.51% NW (Net Weight) which generally a waste from religious activities, followed by kitchen waste with 27.13% NW. The other biggest waste is paper waste with 13.95% NW and plastic waste with 10.50% NW. When observed from the average of waste composition which enters landfill in Bali Province, it is known that the attempt of waste reduction from the source has not been performed effectively. It is implied by the most dominant waste which is biodegradable waste such as leaf/plant waste and kitchen waste. Those type of waste should have been reduced and used from the source or in transporting stage in the 3R landfill or temporary landfill.

4.2. Leachate Quality

Leachate water quality is taken from 10 landfills where the observed parameters are TDS *(Total Dissolve Solid)*, BOD *(Biochemical Oxygen Demand)*, and COD *(Chemical Oxygen Demand)*. From Table 3 it can be seen that Jungut Batu landfill has the highest content of TDS which is 24,810 mg/L and followed by Bengkala landfill with 13,600 mg/L. Total of dissolve solid is the material dissolved in water and does not get filtered by millipore filtering paper with pore size 0.45 µm. This solid is composed of inorganic and organic substances dissolved in water, mineral, and salts.

The main cause of TDS is the inorganic substances in the form of ions generally present in water. The number of BOD and COD is the reference in determining management technology through either the biological process or chemical process. By comparing the number of BOD toward COD, analysis to decide waste management technology can be obtained. By dividing the number of BOD toward COD, it will give information about whether leachate fit to be processed biologically; or it needs leachate water management intervention (chemically or physically). The leachate quality from each landfill as shown in Table 3.

Table 3. Leachate quality

Parameter	Landfills									
	Regional Sarbagita	Regional Bangli	Temesi	Sente	Jungut Batu	Biaung	Mandung	Bengkala	Linggasana	Peh
TDS (mg/L)	3,314	1,375	7,600	7,870	24,810	850	6,660	13,600	1,330	3,880
BOD (mg/L)	985.6	94.55	4,435.2	13,256.9	52.88	6,382.91	2,164	4,365	3,942.4	600.82
COD (mg/L)	1,760	317.44	7,920	22,817.4	897.88	10,873.79	4,400	7,420.5	7,040	1,082.56

Leachate water is obtained through secondary data and also primary data. From Table 3, it can be seen that the parameter of TDS is the parameter that gives a contribution in the form of murky color in leachate water. The highest TDS number can be seen in Jungut Batu landfill which is around 24,810 mg/L. Psychologically, water with murky color is categorized into a lesser quality and can cause pollution around bodies of water. The lowest TDS parameter is Biaung landfill with 850 mg/L.

BOD is the need of oxygen for bacteria to conduct a biochemical process. High level of BOD also causes murky water and contains a lot of organic compounds which also becomes a pollutant agent when released into bodies of water. The highest BOD number is in Sente landfill with 13,256 mg/L and the lowest is in Jungut Batu landfill with 52.88 mg/L.

COD is the need for oxygen to decompose compounds in water using chemical occurrences. The highest COD number is in Biaung landfill with 10.873 mg/L while the lowest is Bangli Regional landfill with 317.44 mg/L.

The ratio between BOD and COD gives information regarding appropriate leachate water management. The ratio of BOD/COD which is higher than 0.5 indicates that the biological process is still suitable to conduct. Meanwhile, if the ratio of BOD/COD is less than 0.5, it implies that the biological process is unable to be conducted or it needs intervention in other management such as advanced physical or chemical management. COD/COD ratio as shown in Fig. 4.

Existing water leachate management in the field of all landfill utilizes stabilization pond which is a biological process. Based on the analysis, Bangli Regional landfill, Jungut Batu landfill, and Mandung landfill should already have advanced more technology for the main purpose of reducing pollution which will be released into bodies of water. The IRBA assessment for each landfill as shown in Table 4.

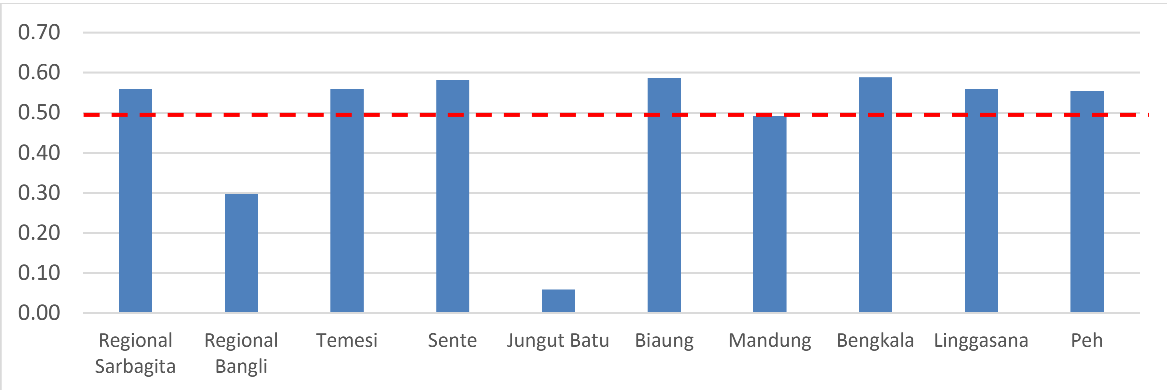

Fig. 4. The ratio of BOD/COD

Table 4. IRBA assessment of 10 landfills in Bali Province

No	Attribute	Risk Index Score									
		Sarbagita Regional Landfill	Bangli Regional Landfill	Temesi Landfill	Sente Landfill	Jungut Batu Landfill	Biaung Landfill	Mandung Landfill	Bengkala Landfill	Linggasana Landfill	Peh Landfill
	I – Site specific criteria										
1	Distance from nearest water supply source (m)	55.2	51.75	51.75	51.75	58.65	58.65	51.75	34.5	37.95	41,4
2	Depth of filling of waste (m)	41.6	38.4	38.4	64	9.6	9.6	32	19.2	19.2	16
3	Area of the landfill (Ha)	51.85	12.2	12.2	12.2	9.15	9.15	6.1	24.4	12.2	12,2
4	Groundwater depth (m)	43.2	0	0	0	13.5	27	0	5.4	8.1	32,4
5	Permeability of soil (1 x 10-6 cm/s)	5.4	5.4	5.4	5.4	5.4	5.4	0	5.4	0	5,4
6	Groundwater quality	37.5	50	50	50	30	30	17.5	50	50	17,5
7	Distance to critical habitats such as wetlands and reserved forest (km)	34.5	0	34.5	27.6	39.1	4.6	34.5	34.5	27.6	34,5
8	Distance to the nearest airport (km)	32.2	0	0	0	6.9	0	0	0	0	4,6
9	Distance from surface water body (m)	34.85	30.75	20.5	24.6	24.6	36.9	32.8	12.3	14.35	12,3
10	Type of underlying soil (% clay)	34.85	32.8	4.1	32.8	36.9	32.8	30.75	30.75	32.8	34,85
11	Life of the site for future use (years)	7.2	3.6	7.2	9	18	18	9	7.2	7.2	7,2
12	Type of waste (MSW/HW)	10.5	10.5	22.5	10.05	3	4.5	10.5	10.5	10.5	10,5
13	Total quantity of waste at site (tons)	25.5	0	3	18	9	7.5	18	25.5	18	19,5
14	Quantity of wastes disposed (tons/day)	18	4.8	2.4	2.4	24	1.2	2.4	19.2	2.4	2,4
15	Distance to the nearest village in the predominant wind (m)	16.8	6.3	2.1	18.9	14.7	16.8	2.1	0	6.3	13,65
16	Flood proneness (flood period in years)	5.6	5.6	6.4	5.6	11.2	12	5.6	5.6	5.6	5,6
17	Annual rainfall at site (cm/year)	6.6	6.6	6.6	5.5	6.6	6.6	0	6.6	6.6	6,6
18	Distance from the city (km)	4.55	4.2	4.2	1.75	4.9	4.9	4.9	2.8	1.75	4,2
19	Public acceptance	3.5	3.5	3.5	3.5	4.9	4.9	3.5	3.5	3.5	3,5
20	Ambient air quality – CH4 (%)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0,3
	II – Related to characteristics of waste at the landfill										
21	Hazardous contents in waste (%)	7.1	7.1	7.1	0	7.1	3.55	7.1	7.1	7.1	7,1
22	Biodegradable fraction of waste at site (%)	52.8	39.6	52.8	49.5	56.1	59.4	52.8	39.6	52.8	52,8
23	Age of filling (years)	46.4	43.5	34.8	34.8	40.6	37.7	46.4	34.8	37.7	37,7
24	Moisture of waste at site (%)	20.8	20.8	20.8	20.8	20.8	19.5	20.8	20.8	20.8	20,8
	III – Related to leachate quality										
25	BOD of leachate (mg/l)	36	36	36	36	18	36	36	36	36	36
26	COD of leachate (mg/l)	19	5.7	19	19	19	19	19	19	19	19
27	TDS of leachate (mg/l)	13	1.3	13	13	13	1.3	1.3	13	13	9,1
	Total	664.8	420.7	458.55	518.1	487.9	467.25	445.1	467.95	450.75	467.1
	Status	High	Low	Moderate	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate

4.3. Status

Based on the assessment result, there are 3 levels of hazard which are highly hazardous, moderate hazardous, and low hazardous. From in Table 4, 2 of 10 landfills are categorized as a low hazardous landfill, 7 are categorized as a moderate hazardous landfill, and 1 is categorized as a highly hazardous landfill. From Fig. 5, it can be seen that the number of IRBA for Sarbagita Regional landfill is the highest which is 664.8.

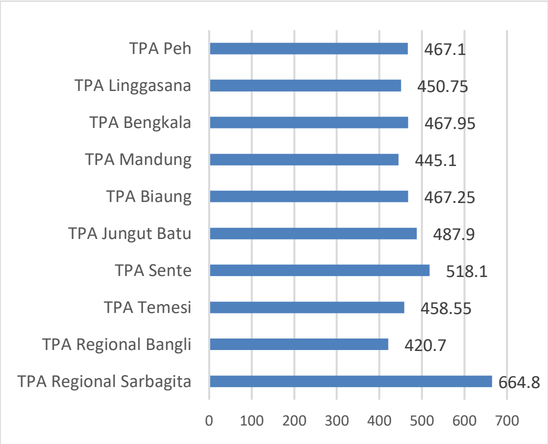

Fig. 5. IRBA assessment recapitulation of 10 landfills in Bali Province

Sarbagita Regional Landfill is a 32.4 hectares open dumping landfill. This landfill is the largest of 10 other landfills since it receives ± 1,400 tons per day waste from 4 cities/regency which are Denpasar City, Badung Regency, Gianyar Regency, and Tabanan Regency. Attributes with the largest contribution of risk index values including distance to settlements, distance to the airport, and distance to the city center. Sarbagita Landfill located in the city center with a very close distance to the airport, which is 10 kilometers and about 1 kilometer to the by-pass road in Denpasar. With a large area and huge waste dumped in Sarbagita Reginal Landfill, the unwell-managed landfill has resulted in a decreasing in the quality of the surrounding environment. Based on the leachate characteristics in Figure 4, it is known that COD is quite high but the Leachate Treatment Plant found in this landfill is still conventional, by stabilization ponds. Recommendation for Sarbagita Regional landfill is to close the dumping site through landfilling in that area and remediation is optional.

The next landfill with the high number is Temesi landfill, Sente landfill, Jungut Batu landfill, Biaung landfill, Bengkala landfill, Linggasana landfill, and Peh landfill. The seven landfills are categorized as a moderate risk landfill with a score ranging from 450-599 with a recommendation to rehabilitate right away the landfill into a sustainable final disposal site. Additionally, Bangli Regional landfill and Mandung landfill are categorized into low-risk landfill with score 300-499 and considered as a potential location to be landfill in the future.

With proper IRBA analysis and leachate water analysis, then there needs revitalization or addition in leachate management technology in Bangli Regional landfill, Jungut Batu landfill, and Mandung landfill to repair the leachate water quality so as to release them into bodies of water around the landfill.

5. CONCLUSION

Risk index of a landfill in Bali Province of 10 landfills has been analyzed. Seven of them are categorized into moderate hazard level which are Temesi landfill, Sente landfill, Jungut Batu landfill, Biaung landfill, Bengkala landfill, Linggasana landfill, and Peh landfill. In the future, those seven landfills could be operated and rehabilitated into sustainable landfill. Two of ten landfills are categorized into low hazard level which is Bangli Regional landfill and Mandung landfill and recommended to rehabilitate the landfills into sustainable landfills in a phased manner. Meanwhile, 1 landfill is categorized into a high risk which is Suwung/Sarbagita Regional Landfill. In the future, the landfill must be closed and there needs to be no more landfilling in the landfill.

6. ACKNOWLEDGMENTS

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