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Non-Point Source Pollution Investigation in Drinking Water Protection Area of Kaoping River Basin, Taiwan

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Abstract: - The Kaoping River basin is the largest and the most intensively used river basin in Taiwan. It is 171-km long, drains a catchment of more than 3,250 km^2. Both point and non-point source (NPS) pollutants are now the causes of biochemical oxygen demand (BOD), nutrients, and suspended solids (SS) in the river. The main water pollution sources are livestock wastewater from hog farms, municipal wastewater, industrial wastewater, and NPS pollutants from agricultural areas. After the implementation of the hog ban in the Drinking Water and Source Water Protection Area (DWSWPA), all of the half million hogs have been removed or relocated in 2001. Thus, the municipal wastewater and NPS pollutants become the major concerns after 2001. In this study, the potential NPS pollution sources located within the DWSWPA in the Kaoping River basin are investigated. Investigation results show that there are 827 potential pollution incidents, which cover 2,610 hectors in the DWSWPA. Orchard farms are the major potential pollutant sources, which cover 60% of the total area of the potential pollutant sources. Moreover, results reveal that mango and betel palm farms dominated the illegal farmland areas, and are scattered around the river corridors. Field investigations indicate that major BOD, total phosphate (TP), total nitrogen (TN), and SS loadings came from the betel palm and orchard farms. The calculated total loadings of BOD, TP, TN, and SS are 69,000, 9,200, 58,500, and 487,500 kg/yr, respectively. Among the four major reaches (Lo-Non, Chi-San, Chu-Ko, and I-Lao creeks), the Lo-Non creek discharge the major pollutant loadings into the Kaoping River. Thus, the highest degree of protection is given to the Lo-Non creek. Results and experience obtained from this study will be helpful in designing the watershed management and NPS pollution control strategies for the Kaoping River basin and other similar river basins.

Key-Words: NPS pollutant, BOD, water quality, watershed management

1 Introduction

In recent years, the general public is becoming increasingly concerned about the drinking water quality leading to more emphases on the management of drinking water sources. After the Government revised and passed the “Drinking Water Management Regulations” on May 21, 1997, the Environmental Protection Administration, Executive Yuan acts based on Article 5 to complete the setup of 77 drinking water source protection zones and 49 additional zones located within a certain distance from the existing drinking water intakes covering a total area of 3,577 sq km. It is about 36% of the total area of all drinking water protection zones and 10% of the total area of Taiwan Island. Since then many development activities within the protection regions have been prohibited or limited. However, with recent changes of our society, private sectors have requested the Government to open up the protected zones for limited development. Thus, the pollutants that may be brought over to the protection zones by the various development activities should be investigated and assessed in order to establish the background information on the various environmental parameter to assist in understanding the impact of the 12 polluting activities [1,2], currently controlled by the Administration in water source protection zones. The results can be useful references and bases to help government agencies and environmental protection offices establish future environmental policies.

Kaoping River Basin is the major drinking water source for the greater Kaohsiung metropolitan region. However, recent pollutions from village and township wastewater, sanitary landfill leachate, non-point source, industrial wastewater discharge and livestock wastewater cause a serious pollution of the river. Our nation has already established a complete information system on point sources but not on non-point sources. Although the main pollution in Kaoping River basin comes from point sources such as municipal wastewater and livestock wastewater, non-point sources (NPS) contribute 10% to 15% of the total pollution based on a conservative estimation. Thus, in addition to point sources, non-point sources must be thoroughly investigated, assessed and managed in order to achieve the objective to improve the drinking water quality in Kaoping River basin for protecting the he drinking water source.

2 Materials and Methods

NPS pollutants are carried over by rainfall and irrigation water to enter a water body dispersedly via surface runoff, intermediate and groundwater flows causing direct or indirect negative impact on the normal use of water resources [3,4]. They are complicate and difficult to assess because many factors such as topography, soil characteristics and rainfall intensity affect their quantity and quality [5,6]. In this project, the assessment of NPS is classified into two categories: agricultural return flow and storm water runoff. The agricultural return flow originates from paddy farm and dry farm land while the storm water runoff comes from orchard, betel palm farm, tea farm forest, mine, road construction, building construction site, golf course, and recreational park. The occurrence and transportation of NPS are rather complicate; they are generated over the entire area and their quantity and quality are obviously affected by local differences. Factors such as rainfall, hydrology, river channel characteristics on as well as transportation of pollutants in the catch basin and river channel must be considered when assessing non-point sources [7]. Additionally, the uncertainty of time-related probability makes the quantification of potential NPS pollutants even more difficult [8].

There are two methods for quantifying the potential NPS loadings: (1) quantitative analyses of the quality of the receiving water body, and (2) quantitative analyses of the pollutants during their surface transportation in the catch basin. The first method analyzes and calculates the total quantity of pollutants received by a water body to estimate the total pollutant output from the watershed. This method, which is based on synchronized monitoring of river water flow and pollutant concentration to calculate the total pollutant loading, requires a large quantity of monitoring data. In reality, continual monitoring for the NPS pollutant loading in a large watershed or many tributaries is difficult to perform. Therefore, the multiple-region method is currently often used for estimating the pollution loading based on the assumptions that both the water quality and quantity in a sub-region do not vary much. The average pollutant concentration for a sub-region and the measured surface runoff are used to calculate the total potential pollution loading for the sub-region. The cumulative pollution loadings for all sub-regions are taken as the total estimated pollution loading for a region as expressed by the following equation:

$$L = \sum_{i}^{n} CiQi$$

Where:

L = the output quantity of a pollutant

Ci = concentration of the pollutant in the ith sub-region

Qi = total surface runoff in the ith sub-region

When setting up the region and designing the monitoring frequency, the following two precautions are important for collecting representative data:

(1) Adequate monitoring frequency and monitoring stations should be designed based on the characteristics and requirements of the study. Generally, the frequency should reflect the various rates of surface runoff quantity and quality.

(2) The quantity of surface runoffs caused by storm water is usually excessive and changes rapidly cause extreme variations of pollutant outputs. Thus, higher monitoring frequencies are needed with synchronized observations. Especially during wet seasons the potential pollution loading caused by the route of large surface runoff constitutes a rather great ratio of the total annual pollution loading. Hence high frequency of monitoring during this period is needed to obtain accurate flow rate and variations of potential pollution loading.

Collecting the information on land use is the first step for estimating the non-point source potential pollution. Based on the percentage of various land uses, e.g. paddy field and dry farmland, the surface run off per unit area is multiplied by the total area to obtain the non-point source flow rate. The generation coefficients for the various pollutants, e.g. biochemical oxygen demand (BOD), total phosphate (TP), total nitrogen (TN), and suspended solids (SS) are subsequently used to multiply the flow rate and then divided by 365 days to calculate the daily quantity of pollutants. The flow rate of storm water discharged into Kaoping River through the storm water draining system is used to evaluate the non-point source pollution and its impact on the water quality of Kaoping River [9-12].

The quantity of pollution may experience some reduction from its source to where it is discharged into the river. The actual quantity of pollution reaching the river is termed "effective loading" while the ratio of effective loading to the total loading of pollution at the source is defined as the percentage of effective loading. The percentage of effective loading, which is closely related to self-purification such as bio-degradation, sedimentation, soil adsorption and percolation, as well as the characteristics of a river or drainage system, e.g., slope, flow rate, surface area, population density, and soil property, can be actually measured on-site using the following procedures:

(1) On-site measuring the water quality and flow rate of discharges from the drainage system into the river to estimate the pollution effective loading.
(2) Estimating the effective loading of pollution at the source for each pollution catching area
(3) Dividing the pollution effective loading by the discharge quantity to obtain the percentage of effective loading of the collecting area.

Since the actual on-site measurement of percentage of effective loading is tedious, time-consuming and manpower-intensity, it is usually estimated based on review of literature, or the information contained in models that have been completed earlier. In this project, the percentage of effective loading will be evaluated by collecting numbers published in literature and reports subject to modifications with modelling [6-10].

3 Pollution Source Investigating

Prior to locating the source of potential pollution, selecting, purchasing, collecting and distributing basic photographic maps must be completed. The first step is to overlap 1/5000th map with the watershed protection area map to locate the name and number of the area selected for studying. For the area located in this study, it covers 36 sheets of 1/5000th photographs and 97 sheets of 1/10000th photographic maps, a total of 133 sheets. As shown in Fig. 1, the area to be investigated locates in the water source protection zone between Kaohsiung Hsien (County) and Pingtung Hsien (County). After screening, 54 sheets of basic photographic maps are used in the investigation

The investigation region is divided into 4sug-regions of Chi-San creek, Lo-Non Creek, Chu-Ko Creek and I-Lao creek. Copies of the basic photographic maps are made available for marking the locations directly on the map. All sources of potential pollution have been marked on the map and then checked on-site for saving time. If the color hue of the basic photographic map is too dark to be conveniently used, the tracing paper that contains the sketches is taped on the map with easy-to-peel tapes. Whether using the sketched tracing paper or copied photographic maps, the location must be marked at the appropriate longitude and latitude lines with pencils for locating the coordinates. Locating the route of investigation beforehand will avoid the problem of not finding the route during location of pollution source causing unnecessary time wasting. There are 12 items activities causing potential pollution or pollution concern in the protection zone as stipulated in Article 5 of the Drinking Water Management Regulations. Since this project targets non-point sources, only the NPS pollution activities in these 12 items are further classified according to land use pattern and the major plant coverage into 12 categories. They are paddy field, dry farm land, orchards, tea plantation, betel palm field, recreation, domestic fowl and animal farm, quarry, construction, mine exploration, mining, horticulture, and others.

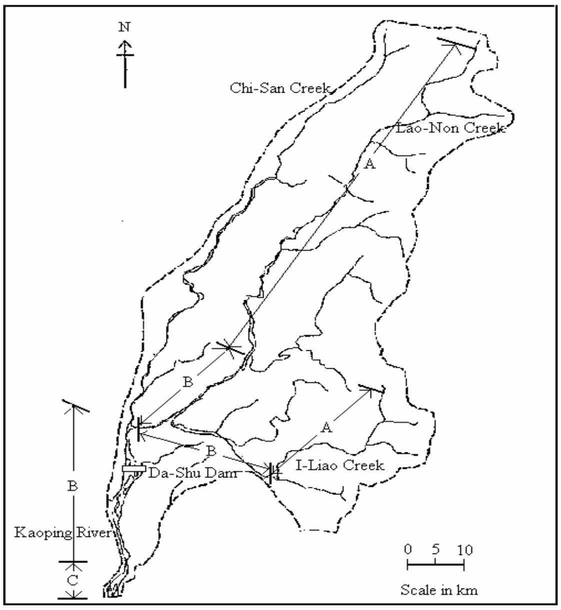

Fig. 1. Kaoping River basin and major reaches.

4 Results and Discussion

Results of the on-site locating and investigation of potential pollution sources in the four major creek sub-regions in the Kaoping River basin show that there are 827 potential pollution incidents located covering an area of 2,610 hectares. Orchards have the greatest pollution potential in the protection zone contributing 50% of all potential pollution incidents covering an area 61% of the total area. Based on the information collected on-site, wax apple and mango are the major fruits planted in orchards. Betel palm farm is the number 2 source of potential pollution constituting 25% of the total pollution incidents in an area 23% of the total basin. The third pollution source comes from dry farm land that contributes 16% of all potential pollution incidents in an area 12% of the total area. Vegetables, peas, melons and corn are the major crops; their non-point source potential pollution is usually insignificant in terms of percentages of both incidents and area covered.

Tables 2 and 3 list statistically the number of various pollution potential incidents and the area involved in the pollution potential incidents, respectively. As the number of pollution potential incident caused by orchards is concerned, Lo-Non Creek sub-region has the highest percentage (42%) followed by I-Lao Creek sub-region (29%), and Chi-San creek sub-region (27%) with Chu-Kou Creek sub-region having the lowest percentage of 2%. When the potential pollution incidents caused by betel palm farm are considered, I-Lao Creek sub-region becomes the largest contributing area (50%). Lo-Non Creek sub-region is the next contributing 26%; Chi-San Creek sub-region is the third contributing 14%. The smallest contributor is Chu-Ko Creek sub-region that contributes 10%. The order of magnitude of the contribution by the various creek sub-regions is arranged as Lo-Non Creek (40%), I-Lao Creek (29%), Chi-San Creek (24%) and Chu-Ko Creek (7%).

As the area covered by the pollution potential incidents is concerned, all orchards in the Lo-Non Creek sub-region is the largest covering 70% of the total area followed by the 20% for Chi-San Creek sub-region, the 9% for I-Lao Creek sub-region and the smallest 1 % for Chu-Ko Creek sub-region. The major contributor to the betel palm faming area is Lo-Non Creek sub-region (48%) indicating that Lo-Non Creek sub-region has a larger farming area for growing a single crop than I-Lao Creek sub-region, which contributes 32% followed by the third Chi-San Creek sub-region) (14%) and the smallest Chu-Ko Creek sub-region (6%). The above data indicate that Lo-Non Creek sub-region is the largest source for non-point source potential pollution in Kaoping River basin water source protection zone.

After the completion of GIS system with input of on-site information, the aforementioned unit area output method is used to estimate the non-point source potential pollution in the water source protection zone. This method is based on the total annual output for a pollutant per hectare area (kg/ha-yr); the watershed must be divided into sub-regions of relatively uniform water uses and thus consistent pollution output. Each sub-region has a different annual of pollution output per unit area. The production of the total area of each sub-region and the annual pollution output per unit area will yield the total pollution output for each sub-region. Adding up all the pollution outputs for all sub-regions, the total pollution output for the entire basin can be obtained. The recommended annual potential pollution output per unit area for the various land uses as published in literature have been collected and screened by the research team of this project and listed in Table 4.

After calculating the total area covered by the various pollution potential activities in Kaoping River Basin water source protection zone, the unit area output method is used to calculate the total quantity of non-point soured potential pollution in the protection zone. The results show that the total discharge quantities of non-point source pollution are 69,019 kg/yr for BOD, 9,197 kg/yr for TP, 58,478 kg/yr for TN, 20,659 kg/yr for NH, and 487,483 kg/yr for SS. Table 5 lists the statistics on the total quantity of pollution potential discharges for the various creek sub-regions in Kaoping River basin water resource protection zone. The percentages of potential pollution contributed by Lo-Non Creek of the total potential pollution from all creek sub-regions are 59% for BOD, 70% for TP, 67% for TN, 70% for NH_3 and 72% for SS. These numbers show that Lo-Non Creek sub-region is the major area that contributes most potential NPS pollution to the water source protection zone. The next major contributor is Chi-San Creek sub-region (BOD 17%□TP 20%□TN 19%□NH_3 19%□SS 16%) followed by I-Lao Creek sub-region (BOD 20%, TP 9%, TN 12%, NH_3 10%, SS 10%). The Chu-Ko Creek sub-region contributes insignificant potential pollution ranging from 1% to 4% for the various pollutants to the total pollution in the region.

Table 6 lists the statistics on the potential pollution for the various polluting activities in the DWSWPA of Kaoping River basin. It shows which polluting activity causes the potential pollution for a particular pollutant. Table 6 shows the source activities for the various potential pollutants; potential BOD pollution mainly stems from betel palm farms (49%) and orchards (41%) with a small portion from dry farm land (8%); potential TP pollution originates from orchards (68%) and dry farm land (28%); potential TN pollution comes from orchards (42%) followed by betel palm farms (15%)

and dry farm land (14%); potential SS emerges from orchards (42%) and dry farmland (30%) followed by construction (16%) and betel farms (12%). Since construction causes an extremely high unit area potential SS pollution, effective management of all construction sites is necessary in the protection zone if the discharge of SS increases.

5 Conclusions

In this study, potential NPS pollution sources located within the DWSWPA in the Kaoping River basin are investigated. The following conclusions can be drawn from this study.

1. Approximately 827 of potential pollution incidents in a total area of 2,610 hectares are observed. Additionally, the unit area output method has been implemented to calculate the NPS pollution discharges. The calculated pollutant loadings include 69,019 kg/yr of BOD, 9,197 kg/yr of TP, 58,478 kg/yr of TN, 20,659 of kg/yr NH_3, and 487,483 kg/y of SS.
2. Results of the investigation indicate that the Lo-Non Creek sub-region is the major area with the most potential pollution in the DWSWPA of Kaoping River basin followed by Chi-San Creek sub-region and I-Lao Creek sub-region. The Chu-Ko Creek sub-region has fewer potential pollution incidents because it has less land development and fewer inhabitants so that its pollution discharges are insignificant as comparing to the total pollution discharges for the whole region.
3. Investigation results also reveals that the potential NPS pollution in the DWSWPA is contributed by fruit orchard farm.
4. The construction site covering a total area of 7,127 m^2 is characterized by its high unit area potential pollution output. Its NPS pollution causes serious adverse impact on the local water body. Hence, optimizing the management of construction sites should be the effort of future implementation.
5. On-site locating and investigation of potential pollution incidents uncovers that the conclusion based on aerial photographs are different from the information collected on-site such that on-site inspection and positioning are necessary.
6. Systematic detailed analyses on the source of potential NPS pollution, categories of pollutants and their distribution characteristics will assist regulatory agencies in understanding the NPS pollution and proposing responsive management policies.
7. The following remedial strategies have been recommended to reduce the impacts of NPS pollution in the DWSWPA in the Kaoping River basin: application of best management practice (BMP) for NPS pollutant control; application of natural treatment systems for the treatment of stormwater runoff; and construction of the watershed geographical information system (GIS) and real time water quality monitoring system to effectively monitor and manage the watershed.

Progress in these and other related areas would be essential if the challenges to river water management and water quality improvements are to be met. Results and experience obtained from this study will be helpful in designing the NPS pollution control strategies for the Kaoping River basin.

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Table1. Quantity of potential yearly pollution per unit area for various land uses.

kg/ha/year	Farm Land	Grass Land	Forest	Orchard	Construction	Recreation
BOD	18	5.5	5	18	50	4.18
TP	4	4	0.2	4	5	1.03
TN	26	26	3	26	8.5	5.08
NH_3	13	13	1.5	13	4.25	2.54

Table 2. Potential incidents for NPS pollution within the DWSWPA in the Kaoping River basin.

		Farm land	Orchard	Tea garden	Betel palm farm	Recreation	Construction	Others
Chi-Shan Creek	incident	37	110	1	29	2	4	10
	%	27%	27%	25%	14%	8%	40%	30%
Lau-Nong Creek	incident	55	168	1	55	10	6	11
	%	39%	42%	25%	26%	40%	60%	32%
Yi-Liao Creek	incident	38	119	2	105	10	0	13
	%	27%	29%	50%	50%	40%	0%	38%
Chuo-Kou Creek	incident	10	8	0	20	3	0	0
	%	7%	2%	0%	10%	12%	0%	0%
Total	incident	140	405	4	209	25	10	34
	%	100%	100%	100%	100%	100%	100%	100%

Table 3. Areas of the various potential pollution incidents within the DWSWPA in the Kaoping River basin.

		Farm land	Orchard	Tea farm	Betel palm farm	Recreation	Construction	Others
Chi-Shan Creek	m^2	742,246	3,084,145	1,272	827,948	267	2,068	1,030
	%	22%	20%	3%	14%	0%	4%	0%
Lau-Non Creek	m^2	2,247,929	11,036,948	36,367	2,718,534	772,837	56,755	282,720
	%	68%	70%	94%	48%	90%	96%	75%
I-Liao Creek	m^2	240,054	1,499,241	1,161	1,837,432	37,402	0	94,105
	%	7%	9%	3%	32%	4%	0%	25%
Chuo-Kou Creek	m^2	97,314	102,024	0	331,733	54,705	0	0
	%	3%	1%	0%	6%	6%	0%	0%
Total	m^2	3,327,543	15,722,358	38,800	5,715,647	865,211	58,823	377,855
	%	100%	100%	100%	100%	100%	100%	100%

Table 4. The annual potential pollution output per unit area for the various land uses.

Land Use Pattern	BOD kg/ha-yr	TP kg/ha-yr	TN kg/ha-yr	NH_3 kg/ha-yr	SS kg/ha-yr
Orchard	18	4	26	13	129.4
Betel palm farm	59.53 (COD)	0.318	14.92	--	100.09
Tea farm	5.5	4	26	--	104.6
Rice paddy	3.2	0.4	0.63	--	129.4
Vegetable farm	18	8	26	--	450
Forestry	5	0.2	3	1.5	85
Construction	602	--	36.9	--	110,954
Grassland	2.7	0.2	0.74	--	58.6
Recreation	4.18	1.03	5.08	2.54	--
Community	50	5	8.5	--	460
Others	--	0.4	1	--	--

Table 5. Potential NPS discharges for the various river sections within the DWSWPA in the Kaoping River basin.

		Chi-San River	Lo-Non River	I-Lao River	Chu-Ko River	Total
BOD	(kg/yr)	11,741	40,836	14,085	2,356	69,019
	%	17%	59%	20%	3%	100%
TP	(kg/yr)	1,815	6,389	858	135	9,197
	%	20%	70%	9%	1%	100%
TN	(kg/yr)	11,057	39,086	7,294	1,041	58,478
	%	19%	67%	12%	2%	100%
NH_3	(kg/yr)	4,009	14,544	1,959	147	20659
	%	19%	70%	10%	1%	100.00%
SS	(kg/yr)	79,969	349,888	48,606	9,020	487,483
	%	16%	72%	10%	2%	100%

Table 6. NPS pollution caused by the various polluting activities

Farmland	(kg/yr)	5,882	2,607	8,471	--	147,345
	%	8%	28%	14%	--	30%
Orchard	(kg/yr)	28,300	6,289	40,878	20,439	203,447
	%	41%	68%	70%	99%	42%
Tea farm	(kg/yr)	21	16	101	--	406
	%	0%	0%	0%	--	0%
Betel palm farm	(kg/yr)	34,025	182	8,528	--	57,208
	%	49%	2%	15%	--	12%
Recreation	(kg/yr)	362	89	440	220	--
	%	1%	1%	1%	1%	--
Construction	(kg/yr)	429	0	26	--	79,077
	%	1%	0%	0%	--	16%
Others	(kg/yr)	--	14	35	--	--
	%	--	0%	0%	--	--
Total	(kg/yr)	69,019	9,197	58,479	20,659	487,483
	%	100%	100%	100%	100%	100%