METHODOLOGY FOR IDENTIFYING PESTICIDE HOTSPOTS: THE CASE OF BANGLADESH

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I. Introduction

The purpose of this learning module is to provide the user with an analytical tool for the identification and targeting of areas of high pesticide use intensity, in lieu of access to detailed information on farm-level pesticide use for all areas of concern. The tool leverages readily available information on agricultural production (usually from a Census) and combines this with pesticide use information (usually from farm-level surveys) to predict pesticide use for larger geographical coverage. Policymakers and agricultural practitioners will find this tool useful for the identification of these areas for monitoring and extension activities.

As a brief introduction to the procedure, Figure 1 decomposes the basic steps involved in calculating pesticide use. The first step is to assemble information on agricultural production for the crops and areas which are of interest. This information is normally available through the country’s Census data, or through an agricultural ministry. The second step is to assemble information on pesticides that are used to produce that particular crop. Farm-level surveys typically contain this information, however, in its absence one may chose (with appropriate assumptions) to use pesticide use intensities from other studies conducted in similar areas (for example, in another location within the same country, or neighboring country).

The third step is to combine these two pieces of information to calculate intensities, and fourthly to project these estimates to all areas of interest. The final step presented in this module is to then link these results to a GIS-based tool for graphical observation and analysis.

Note that the only software skills required for this exercise is some basic knowledge of spreadsheet software. The procedure is the same and can be performed in any package. For the example outlined below we use Microsoft Excel, however for those more proficient in database software (such as MS ACCESS), this can also be done in this type of software as well. Also note that for this exercise, we made use of recent farm-level survey data from Bangladesh\(^1\) on pesticide use and agricultural production data from the Ministry of Agriculture, Bureau of Statistics for the years 1994 and 1999. The example uses pesticide application information for rice in one district, Rajshahi, and then projects these use intensities to all districts reporting rice agricultural production.

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\(^1\) Survey conducted by the Development Economics Research Group, Infrastructure and Environment Department of the World Bank in the summer of 2003.
1. Production data

The first step is to select the crop and area under investigation. For our simplified example, we have selected rice as our crop of interest in the district of Rajshahi, Bangladesh. Although our example only uses one crop and one area, multiple crops and areas can be calculated simultaneously by simply performing each step for all crops and areas. Throughout the example, we will make reference to the included Excel spreadsheet file named “Bangladesh pesticide intensity calculation.xls”.

2. Pesticide use information

- Pesticide use by crop
- Source: Farm-level survey data

3. Calculation of pesticide intensities

- Calculation of pesticide quantities
- Calculation of intensities (pesticide use per unit of production)

4. Projection to other areas

- Calculation of total pesticide use per selected crop and area

5. Linking to GIS

- Intuition & descriptive statistics
- Linking with GIS

Figure 1: Flowchart of steps in calculating pesticide intensity
In the first tab, “Survey production data”, sample survey production data are provided for rice with the following format:

<table>
<thead>
<tr>
<th>Farm unit</th>
<th>Crop name</th>
<th>Crop code</th>
<th>Production (in kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>241 BORO</td>
<td>Rice</td>
<td>10</td>
<td>1360</td>
</tr>
<tr>
<td>245 BORO</td>
<td>Rice</td>
<td>10</td>
<td>320</td>
</tr>
<tr>
<td>246 BORO</td>
<td>Rice</td>
<td>10</td>
<td>4000</td>
</tr>
<tr>
<td>247 BORO</td>
<td>Rice</td>
<td>10</td>
<td>560</td>
</tr>
<tr>
<td>248 BORO</td>
<td>Rice</td>
<td>10</td>
<td>640</td>
</tr>
<tr>
<td>249 BORO</td>
<td>Rice</td>
<td>10</td>
<td>800</td>
</tr>
<tr>
<td>250 BORO</td>
<td>Rice</td>
<td>10</td>
<td>680</td>
</tr>
<tr>
<td>251 BORO</td>
<td>Rice</td>
<td>10</td>
<td>1200</td>
</tr>
<tr>
<td>252 BORO</td>
<td>Rice</td>
<td>10</td>
<td>200</td>
</tr>
<tr>
<td>253 BORO</td>
<td>Rice</td>
<td>10</td>
<td>1600</td>
</tr>
<tr>
<td>254 BORO</td>
<td>Rice</td>
<td>10</td>
<td>1120</td>
</tr>
<tr>
<td>255 BORO</td>
<td>Rice</td>
<td>10</td>
<td>400</td>
</tr>
<tr>
<td>260 AMAN</td>
<td>Rice</td>
<td>10</td>
<td>960</td>
</tr>
<tr>
<td>262 BORO</td>
<td>Rice</td>
<td>10</td>
<td>800</td>
</tr>
<tr>
<td>263 BORO</td>
<td>Rice</td>
<td>10</td>
<td>720</td>
</tr>
<tr>
<td>266 BORO</td>
<td>Rice</td>
<td>10</td>
<td>3000</td>
</tr>
<tr>
<td>267 AMAN</td>
<td>Rice</td>
<td>10</td>
<td>2800</td>
</tr>
<tr>
<td>268 BORO</td>
<td>Rice</td>
<td>10</td>
<td>1480</td>
</tr>
<tr>
<td>272 IRRI</td>
<td>Rice</td>
<td>10</td>
<td>800</td>
</tr>
</tbody>
</table>

Note that the column labeled “Farm unit” represents each farm unit, with production in kilograms of rice produced on that farm. In this particular example of Bangladesh there are several varieties of rice (e.g. BORO, AMAN, IRRI, etc.), however, to keep the exercise simple we consider them as an aggregate group called “Rice”.

2. Pesticide use information

The second tab, “Survey pesticide data”, contains information on pesticide use for each farm and crop. Note below that this time “Farm unit” may be repeated more than once since the farmer uses more than one pesticide on that particular crop. The procedure will require us to sum across all pesticides for each crop and farm unit. It may also be the case that the physical state of the pesticide will vary whether it is a solid or liquid, thus in this case there are two quantity columns, one denoted in kilograms (kg) and one in milliliters (ml):

<table>
<thead>
<tr>
<th>Farm unit</th>
<th>Survey Area</th>
<th>Crop name</th>
<th>Crop code</th>
<th>Production (in kg)</th>
<th>Quantity of solid application (in kg)</th>
<th>Quantity of liquid application (in ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>241 RAJSHAHI</td>
<td>BORO</td>
<td>Rice</td>
<td>10</td>
<td>1360</td>
<td>6.00</td>
<td>0</td>
</tr>
<tr>
<td>241 RAJSHAHI</td>
<td>BORO</td>
<td>Rice</td>
<td>10</td>
<td>1360</td>
<td>0.00</td>
<td>200</td>
</tr>
<tr>
<td>245 RAJSHAHI</td>
<td>BORO</td>
<td>Rice</td>
<td>10</td>
<td>320</td>
<td>0.00</td>
<td>100</td>
</tr>
<tr>
<td>246 RAJSHAHI</td>
<td>BORO</td>
<td>Rice</td>
<td>10</td>
<td>4000</td>
<td>0.20</td>
<td>0</td>
</tr>
</tbody>
</table>
In addition to the difference between solids and liquids, pesticides also vary according to their formulation and relative toxicity. Pesticides are normally applied as a formulation or mixture with two components 1) an active ingredient (or ai) which is the base elemental chemical in the pesticide used to fight pests, and 2) a “carrier” chemical which is combined to create a formulation designed for a specific use. Normally the carrier chemical is a relatively benign substance used to dilute the relative toxicity of the active ingredient in the formulation, therefore our calculations account for only the amount or concentration of active ingredient in a formulation. In our data set, this percentage of active ingredient in the formulation is indicated in the column labeled “% ai”. For example, farm unit #241 in the first row, we see that 6 kg (column G) of furadan (column J) were used. Furadan is the trade or commercial name known to farmers who buy the product. The active ingredient for furadan is carbofuran (column I) where the % ai content is 0.05 (or 5%), which implies that 0.3 kg (6 kg x 0.05) of carbofuran were used in this particular application of furadan on rice. To reiterate, it is arguably more important to account for active ingredients used in pesticide use analyses than simply the total amount of pesticide formulation used, especially when one is concerned about the potential health consequences of such use.

<table>
<thead>
<tr>
<th>Farm unit</th>
<th>Crop name</th>
<th>Crop</th>
<th>Quantity of solid application (in kg)</th>
<th>Quantity of liquid application (in ml)</th>
<th>Chemical name</th>
<th>Commercial name</th>
<th>Chemical Abstract Service no.</th>
<th>% ai</th>
</tr>
</thead>
<tbody>
<tr>
<td>241</td>
<td>BORO</td>
<td>Rice</td>
<td>6.00</td>
<td>0</td>
<td>Carbofuran</td>
<td>FURADAN</td>
<td>1563-66-2</td>
<td>0.05</td>
</tr>
<tr>
<td>241</td>
<td>BORO</td>
<td>Rice</td>
<td>0.00</td>
<td>200</td>
<td>Fenitrothion</td>
<td>SUMITHION</td>
<td>122-14-5</td>
<td>0.50</td>
</tr>
<tr>
<td>245</td>
<td>BORO</td>
<td>Rice</td>
<td>0.00</td>
<td>100</td>
<td>Fenitrothion</td>
<td>SUMITHION</td>
<td>122-14-5</td>
<td>0.50</td>
</tr>
<tr>
<td>246</td>
<td>BORO</td>
<td>Rice</td>
<td>0.20</td>
<td>0</td>
<td>Carbendazim</td>
<td>SUPER COLOR</td>
<td>10605-21-7</td>
<td>0.50</td>
</tr>
<tr>
<td>246</td>
<td>BORO</td>
<td>Rice</td>
<td>8.00</td>
<td>0</td>
<td>Carbofuran</td>
<td>FURADAN</td>
<td>1563-66-2</td>
<td>0.05</td>
</tr>
</tbody>
</table>

The second consideration on differences in pesticides is its relative toxicity. Since pesticides are not the same in regards to their potency or relative toxicity, we take this into account by using a benchmark standard called the LD$_{50}$ or lethal dose (50%). The

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2 The concentration of active ingredient in a formulation is normally indicated on the label of the pesticide container and is expressed in terms of a volumetric measure. For example, Furadan 50 EC is interpreted as 50 grams of carbofuran per container volume or 0.05 per kg (or 5% of 1kg).

3 The international community has identified 12 particular active ingredients that are particularly hazardous to human health also known as Persistent Organic Pollutants or POPs. POPs are chemical substances that persist in the environment, bio-accumulate through the food web and pose a risk of causing adverse effects to human health and the environment. With the evidence of long-range transport of these substances to regions where they have never been used or produced and the consequent threats they pose to the environment of the whole globe, the international community has now, at several occasions called for urgent global actions to reduce and eliminate releases of these chemicals. Currently there are 12 listed substances, also known as the “dirty dozen”: Aldrin, DDT, Dieldrin, Endrin, Chlordane, Heptachlor, Hexachlorobenzene, Mirex, Toxaphene, PCBs, PCDDs and PCDFs.
LD₅₀ value is a statistical estimate of the number of milligrams (mg) of toxicant per kilogram (kg) of bodyweight required to kill 50% of a large population of test animals. What this implies is that a lower LD₅₀ is more hazardous. Extensive epidemiological studies have been conducted to arrive at these numbers, and they provide us with a convenient measure of comparing the use of one pesticide over another from a health-hazard perspective. Returning to farm unit #241 in the first row, we see that the Human acute oral LD₅₀ for carbofuran is 8 mg/kg, which literally means that oral ingestion of carbofuran at a rate of 8 mg per kilogram of a person’s bodyweight will kill 50% of the test subjects. Relatively speaking, this is a very small amount and is considered highly hazardous to humans. A more readily interpretable version of relative toxicity has been constructed by the World Health Organization (WHO), by classifying substances according to their relative toxicity: Ia (extremely hazardous), Ib (highly hazardous), II (moderately hazardous), III (slightly hazardous), and U (unlikely to pose any acute health hazard).⁴

<table>
<thead>
<tr>
<th>Farm unit</th>
<th>Crop</th>
<th>Crop name</th>
<th>Chemical name</th>
<th>Commercial name</th>
<th>Chemical Abstract Service no.</th>
<th>% ai</th>
<th>Human: acute oral LD₅₀ (mg/kg)</th>
<th>WHO Toxicity class</th>
</tr>
</thead>
<tbody>
<tr>
<td>241</td>
<td>BORO</td>
<td>Rice</td>
<td>Carbofuran</td>
<td>FURADAN</td>
<td>1563-66-2</td>
<td>0.05</td>
<td>8.0</td>
<td>Ib</td>
</tr>
<tr>
<td>241</td>
<td>BORO</td>
<td>Rice</td>
<td>Fenitrothion</td>
<td>SUMITHION</td>
<td>122-14-5</td>
<td>0.50</td>
<td>250.0</td>
<td>II</td>
</tr>
<tr>
<td>245</td>
<td>BORO</td>
<td>Rice</td>
<td>Fenitrothion</td>
<td>SUMITHION</td>
<td>122-14-5</td>
<td>0.50</td>
<td>250.0</td>
<td>II</td>
</tr>
<tr>
<td>246</td>
<td>BORO</td>
<td>Rice</td>
<td>Carbendazim</td>
<td>SUPER COLOR</td>
<td>10605-21-7</td>
<td>0.50</td>
<td>6400.0</td>
<td>U</td>
</tr>
<tr>
<td>246</td>
<td>BORO</td>
<td>Rice</td>
<td>Carbofuran</td>
<td>FURADAN</td>
<td>1563-66-2</td>
<td>0.05</td>
<td>8.0</td>
<td>Ib</td>
</tr>
</tbody>
</table>

To briefly sum up the previous two sections, the information we will require to calculate pesticide intensities will be the amount of crop produced (from the first tab “Survey production data”), the amount of pesticide applied, the commercial name of the formulation, the chemical name of the active ingredient associated with that formulation, the percentage of active ingredient in the formulation and the Human oral LD₅₀ value (all from the second tab “Survey pesticide data”).

3. Calculation of pesticide intensities

Step 1. Calculation of pesticide quantities (contained in the Excel tab “Survey pesticide data”)

Scrolling to the right to column W, we first derive the total amount of active ingredient applied as:

$$\text{Pesticide amount (column G)} \times \text{ % ai (column L)} = \text{Total amount of ai (column W)}$$

⁴ LD₅₀ values for most common pesticides can be found in “The WHO Recommended Classification of Pesticides by Hazard and Guidelines to Classification” available at: http://www.who.int/ipcs/publications/pesticides_hazard/en/
For example, for farmer #241:

\[
6 \text{ kg} \times 0.05 = 0.30 \text{ kg of carbofuran}
\]

The procedure is the same for liquid pesticides contained in column X, by multiplying columns H and L. For farmer #241, the second row contains the liquid pesticide application:

\[
200 \text{ ml} \times 0.50 = 100 \text{ ml of fenitrothion}
\]

At a later stage we will be adding up kg and ml of pesticides for all farmers, therefore it will be convenient to convert them into a single measurement unit. To do this we can make use of the fact that the % ai for liquids is the effective amount of solid active ingredient dissolved in the solution. Therefore, we can add kg and ml by dividing ml by 1000 and adding this with solids in kg:

\[
\text{Solids (column W)} + \frac{\text{Liquids (column X)}}{1000} = \text{Total amount of ai (column Y)}
\]

For farmer #241, in row 2:

\[
0 \text{ kg} + \frac{100 \text{ ml}}{1000} = 0.100 \text{ kg of fenitrothion}
\]

To account for the relative toxicity (risk) of the pesticide, we then multiply our amounts calculated above by the LD$_{50}$ factor. The exact measure we adopt is 1/ LD$_{50}$ as this will effectively give more weight to those substances that are more toxic in nature. Returning to the two pesticides used for farmer #241, we have:

\[
\text{Total pesticide amount (column Y)} \times \frac{1}{\text{LD50 (1/ column U)}} = \text{Risk-weighted total ai (column Z)}
\]

\[
0.30 \text{ kg of carbofuran} \times \frac{1}{8.0} = 0.0375 \text{ kg of risk-weighted carbofuran}
\]

\[
0.10 \text{ kg of fenitrothion} \times \frac{1}{250.0} = 0.0004 \text{ kg of risk-weighted fenitrothion}
\]

**Step 2. Calculation of pesticide intensities (contained in tab “Simulation”)**

With the two main components of agricultural production and pesticide use, we can now proceed to the calculation of pesticide intensities. We make use of the simple formula:

\[
\text{Pesticide intensity} = \frac{\text{Pesticide amount (numerator)}}{\text{Production of rice (denominator)}}
\]
Pesticide amounts (the numerator) were just calculated as the un-weighted and risk-weighted amounts of active ingredients for each pesticide. To get the overall pesticide intensity for rice, we simply sum each column we derived above, across all pesticides to get the total amount used on rice:

For example, in column C, in the tab “Simulation”, we calculate total ai (column Y of the tab “Pesticide use data”), with the following command:

```
SUM('Survey pesticide data'!Y2:Y265)
```

(in column C in tab “Simulation”)

Performing this summation command for each of the 2 columns Y and Z (with the results contained in column C in the tab “Simulation”), we have the total amounts for each of the 2 indicators (Total ai and Total risk-weighted ai). Similarly, if we perform the same column sum for the crop data in the first tab, “Survey production data”, we have our denominator for the intensity calculation.

```
SUM('Survey production data'!E2:E142)
```

(in column D in tab “Simulation”)

We can now compute intensities by normalizing (dividing) pesticide amount by agricultural production as:

\[
\frac{\text{Pesticide amount}}{\text{production}} = \text{pesticide intensity}
\]

For example for Total ai:

\[
\frac{73,445 \text{ kg of ai}}{254,340 \text{ kg of rice}} = 0.000289 \text{ kg of ai per kg of rice produced}
\]

Likewise, the procedure is the same for the risk-weighted indicator. Pesticide intensities may appear small, however this is a direct result of accounting for only the active ingredient portion of the pesticide formulation, as well as the units being denominated in kg of rice output. One could simply multiply the intensity by 1000 to arrive at, say, 0.289 kg of ai per 1000 kg of rice produced, if the number makes more sense to the intended audience.

### 4. Projection to other areas of interest

Given the total and risk-weighted intensities we calculated for rice, we are now ready to use these with agricultural production data for other areas of interest. Recall that the data we used to calculate the intensities were sample data from one district, Rajshahi. As a bit of a reminder, it is quite often the case that we may not have pesticide data that covers all
areas of interest, and in this exercise we only use pesticide data from Rajshahi. Thus the intensities were calculated based upon the district’s sample survey data, and with the assumption that farmers in other districts of Bangladesh have the same rates of pesticide use for rice, we can use Rajshahi’s intensities to extrapolate to the other districts of Bangladesh. Ideally, one would want to obtain pesticide use information for each geographical location of interest (all districts) and calculate intensities for each district. This would account for any variation in district pesticide intensity.

Returning to our example, in columns I and J in the tab “Simulation” we have rice production data for 23 districts of Bangladesh for the years 1994 and 1999. We can simply multiply the found intensities by the production data for each district to arrive at the total ai used in each district for rice as:

\[
\text{Total ai intensity} \times \text{Production} = \text{Total kg of ai used for rice production}
\]

For example, for the district of Bandarban, we have:

\[
0.000289 \times 6,330 \text{ kg of rice produced} = 1.8280 \text{ kg of ai used on rice}
\]

Repeating this calculation for each of the two intensities, for each district, and for each year, we can see the trend in pesticide use for each area of interest. The results are contained in columns K and L for 1994 and columns M and N for 1999. The last column O, calculates the percentage change in total ai across the two time periods. Note that there is significant variation, with the largest being for the district of Khagrachhari (a 295% increase) and the lowest Patuakhali (a decrease of 80%).

Accounting for risk factors, the district of Kishoreganj is identified as having the largest amount of toxic substances in 1994, whereas in 1999 it is Rangpur. Granted, this is not entirely surprising since these two districts are the highest in terms of rice production, therefore since intensities are scale-dependent on production, they rank as the highest in both categories of un-weighted and risk-weighted pesticide use. As mentioned above, if pesticide use data were available for each district, then one could calculate each of the two intensities for each district, and thus account for any geographical variation in pesticide use. For the purposes of this exercise, we keep it simple by using only one district, Rajshahi, and one crop, rice.

5. Linking to GIS

Other than the descriptive statistics one can derive, another complementary way to interpret data is through visual aids such as Geographical Information Systems or GIS. GIS is a database tool that maps data according to where informational differences may lie geographically or through space. This data can be delineated through administrative, socio-economic or environmental boundaries depending on the intended interest or even policy intervention (for example through taxes/subsidies on the farm unit
With the spreadsheet tabs derived above, one can simply import these results into a GIS package for visual interpretation. Although each package will have its specific procedures for importation and mapping, we provide a basic outline below using the GIS package ArcView by ESRI.

The first step is to import the data into the GIS, normally by converting the data from Excel to another format such as .dbf. Upon importation, one can create alternative themes by which to interpret the data. Using our example, the theme displayed below in Figures 1 and 2 is for rice production for all the districts we included in our projections. Within each theme, we can then highlight one specific column from our spreadsheet and display that information. Figures 1 and 2 present total ai use for each district in 1994 and 1999, respectively. Upon comparison, figure 2 reveals a clear increase in use by 1999, particularly in Rangpur, Rajshahi, Kishoreganj and Comilla.
Using the calculated percentage difference between 1994 and 1999, figure 3 maps those results where the largest decrease in pesticide use was in Patuakhali and the largest increase was in Barisal, Khagrachhari and Kushtia.

Figure 3. Percentage change in pesticide use 1994-1999.